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Control of TRS Emissions from Existing Mills

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16. ABSTRACT

Guidelines to aid the States in their preparation of plans for the control of emissions of total reduced sulfur (TRS) from existing kraft pulp mills are being published under the authority of section 111(d) of the Clean Air Act. TRS emissions from kraft pulp mills are extremely odorous, and there are numerous instances of poorly controlled mills creating public odor problems. Adoption of these emission guidelines by the States would result in an overall reduction of about 80 percent in nationwide TRS emissions from kraft pulp mills.

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Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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For Existing Kraft Pulp Mills

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1. INTRODUCTION

1.1 PURPOSE OF DOCUMENT

This document has been prepared in accordance with regulations established under Section 111(d) of the Clean Air Act. Under the regulations, EPA has established procedures whereby states submit plans to control existing sources of "designated pollutants". Designated pollutants are pollutants which are not included on a list published under Section 108(a) (National Ambient Air Quality Standards) or 112(b)(1)(A) (Hazardous Air Pollutants), but to which a standard of performance for new sources applies under Section 111. Under Section 111(d), emission standards are to be adopted by the states and submitted to EPA for approval. The standards will limit the emissions of designated pollutants from existing facilities which, if new, would be subject to the standards of performance for new stationary sources. Such facilities are called "designated facilities".

In accordance with Section 111 of the Clean Air Act, standards of performance (NSPS) for eight source categories in the kraft pulp industry were promulgated on February 23, 1978. The standards include emission limits for total reduced sulfur (TRS) and particulates. TRS is a designated pollutant. This document is therefore being prepared to establish criteria by which the states may develop emission standards for designated facilities.

Subpart B of 40 CFR 60 contains the procedures under which states submit these plans to control existing sources of designated pollutants. Subpart B requires the states to develop plans for the control of designated pollutants within Federal guidelines. As indicated in Subpart B, EPA will publish guidelines documents for development of state emission standards simultaneous with promulgation of any new source standard of performance for a designated pollutant. These guidelines will apply to designated facilities which emit those designated pollutants and will include useful information for states, such as discussion of the pollutant's effects, description of control techniques and their effectiveness, costs, and potential impacts. Finally, as guidance for the states, recommended emission limits (emission guidelines) and times for compliance are set forth and control equipment which will achieve these emission limits is identified.

After publication of the final guideline document for the pollutant in question, the States will have nine months to develop and submit plans for control of that pollutant from designated facilities. Within four months after the date for submission of plans, the Administrator will approve or disapprove each plan (or portions thereof). If a state plan (or portion thereof) is disapproved, the Administrator will promulgate a plan (or portion thereof) within six months after the date for plan submission. These and related provisions of subpart B are basically patterned after Section 110 of the Act and 40 CFR Part 51 (concerning adoption and submittal of state implementation plans under Section 110).

As discussed in the preamble to Subpart B, a distinction is drawn between designated pollutants which may cause or contribute to endangerment of public health (referred to as "health-related pollutants") and those for which adverse effects on public health have not been demonstrated (referred to as "welfare-related pollutants"). For health-related pollutants, emission standards and compliance times in state plans must ordinarily be at least as stringent as the corresponding emission guidelines and compliance times in EPA's guideline documents. As provided in Subpart B, states may apply less stringent requirements for particular facilities or classes of facilities when economic factors or physical limitations make such application significantly more reasonable. Such justification may include unreasonable control costs resulting from plant age, location, process design, or the physical impossibility of installing the specified control system. States may also relax compliance time if sufficient justification is proven. Such justification may include unusual time delays caused by unavailability of labor, climatological factors, scarcity of strategic materials, and large work backlogs for equipment vendors or construction contractors.

For Welfare-related pollutants, states may balance the emission guidelines, times for compliance, and other information provided in a guideline document against other factors of public concern in establishing emission standards, compliance schedules, and variances provided that appropriate consideration is given to the information presented in the guideline document and at public hearing(s) required by Subpart B and that all other requirements of Subpart B are met. Where sources of pollutants that cause only adverse effects to crops are located in non-agricultural areas, for example, or where residents of a community depend on an economically marginal plant for their livelihood, such factors may be taken into account (in addition to those that would justify variances if a health-related pollutant was involved). Thus, states will have substantial flexibility to consider factors other than technology and costs in establishing plans for the control of welfare-related pollutants if they wish.

For reasons discussed in Chapter 2 of this document, the Administrator has determined that TRS emissions from kraft pulp mills may cause or contribute to endangerment of the public welfare but that adverse effects on public health have not been demonstrated. As discussed above, this means that TRS emissions will be considered a welfare-related pollutant and the states will have greater flexibility in establishing plans for the control of TRS than would be the case if public health might be affected.

This state guidelines document briefly discusses the effects of reduced sulfur compounds on health, and on crops, materials, and animals. Eight process categories having reduced sulfur emissions are discussed. The greatest emphasis, however, has been placed on the technical and economic evaluation of control techniques that are effective in reducing total reduced sulfur emissions, with particular emphasis on retrofitting existing mills. Section 6.2 proposes several control systems available to the states. The costs of these control systems is analyzed in Chapter 8, while Chapter 9 assesses the environmental and energy impact of these control systems. Finally, as guidance for the states, recommended emission limitations are set forth and control equipment which will achieve these emission limitations is suggested.

1.2 TOTAL REDUCED SULFUR COMPOUNDS AND THEIR CONTROL

For purposes of new sorces performance standards (NSPS) and the attendant requirements of Section 111(d), "total reduced sulfur" (TRS) is the designated pollutant to be controlled. TRS in this document refers to a combination of compounds consisting primarily of hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide. Control of TRS emissions at kraft pulp mills is well demonstrated by proper operation of the combustion sources or incineration of the exhaust gases.

The limited information currently available on the health and welfare effects of TRS generally deals with hydrogen sulfide (H_2S). Adverse health effects are noticeable down to 20 ppmv, but this concentration is much higher than expected in the ambient air as a result of even uncontrolled TRS emissions from kraft pulp mills. H_2S at concentrations down to a few parts per billion is recognized as an odor nuisance. The OSHA occupational exposure maximum for H_2S is 20 ppmv, not to be exceeded at any time.

1.3 STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES

In accordance with Section 111 of the Clean Air Act, standards of performance for eight affected facilities or emission sources in the kraft pulping industry have been promulgated (Subpart BB of 40 CFR Part 60). These sources are the recovery furnace (both straight kraft and cross-recovery furnaces)*, digester system, multiple-effect evaporator system, lime kiln, brown stock washer system, black liquor oxidation system, smelt dissolving tank, and condensate stripper system. Information and emission data collected during development of the proposed new source performance standards indicate that best demonstrated control technology can limit the TRS emissions to five parts per million by volume dry gas basis for all new sources except lime kilns and cross-recovery furnaces, which can be limited to 8 ppm and 25 ppm, respectively.

Water treatment ponds, however, are not covered by the proposed NSPS because data on actual TRS emissions are not available and accurate sampling methods for determining TRS and other odorous emissions from treatment ponds are not sufficiently developed or demonstrated. Therefore, water treatment ponds will not be covered in this document.

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*NOTE: Throughout the document, the term "recovery furnaces" will imply both straight kraft recovery furnaces and cross-recovery furnaces, unless otherwise specified.

1.4 EMISSION GUIDELINES

1.4.1 Recommended TRS Emission Limitations for the States

Emission guidelines for control of TRS emissions that may be achieved by application of best adequately demonstrated technology to existing facilities are listed in Table 1-1. These emission guidelines are less stringent in some cases than the standards proposed for new sources since the application of the best adequately demonstrated technology for new sources could result in excessive control costs at existing sources. However, emission guidelines do require the same type of control as judged to be best adequately demonstrated technology for new sources for the three major TRS sources (recovery furnace, digester system, and multiple-effect evaporator system). The justification for these emission guidelines are discussed more completely in Chapters 8 and 9.

Adoption of these guidelines would result in an overall nationwide TRS emission reduction of about 82 percent.

Table 1-1. TRS EMISSION GUIDELINES FOR EXISTING KRAFT PULP MILLS

Affected Facility	Emission Guidelines[1]
Recovery Furnace[2]	
Old Design Furnaces[3]	20 ppm
New Design Furnaces[4]	5 ppm
Cross Recovery Furnaces	25 ppm
Digester System	5 ppm
Multiple-Effect Evaporator System	5 ppm
Lime Kiln	20 ppm[5]
Brown Stock Washer System	No Control
Black Liquor Oxidation System	No Control
Condensate Stripper System	5 ppm
Smelt Dissolving Tank	0.0084 g/kg BLS

[1] Guidelines given are in terms of twelve-hour averages, e.g., from midnight to noon. These are not "running" averages, but are instead for discrete contiguous twelve-hour periods of time.

[2] One percent of all twelve-hour TRS averages per quarter year above the specified level, under conditions of proper operation and maintenance, in the absence of start-ups, shutdowns and malfunctions, are not considered to be excess emissions.

[3] Furnaces not constructed with air pollution control as an objective (see definitions on pages 6-7 and 10-3).

[4] Furnaces designed for low TRS emissions and having stated in their contracts that they were constructed with air pollution control as an objective (see definitions on pages 6-7 and 10-3).

[5] Two percent of all twelve-hour TRS averages per quarter year above 20 ppm, under conditions of proper operation and maintenance, in the absence of start-ups, shutdowns and malfunctions, are not considered to be excess emissions.

2. HEALTH AND WELFARE EFFECTS OF TOTAL REDUCED SULFUR COMPOUNDS

2.1 INTRODUCTION

In accordance with 40 CFR 60.22(b), promulgated on November 17, 1975 (40 FR 53340), this chapter presents a summary of the available information on the potential health and welfare effects of total reduced sulfur (TRS) compounds and the rationale for the Administrator's determination that TRS is a welfare-related pollutant for purposes of section 111(d) of the Clean Air Act.

The Administrator first considers potential health and welfare effects of a designated pollutant in connection with the establishment of standards of performance for new sources of that pollutant under section 111(b) of the Act. Before such standards may be established, the Administrator must find that the pollutant in question "may contribute significantly to air pollution which causes or contributes to the endangerment of public health or welfare" [see section 111(b)(1)(a)]. Because this finding is, in effect, a prerequisite to the same pollutant being identified as a designated pollutant under section 111(d), all designated pollutants will have been found to have potential adverse effects on public health, public welfare, or both.

As discussed in section 1.1 of this document, Subpart B of Part 60 distinguishes between designated pollutants that may cause or contribute to endangerment of public health (referred to as "health-related pollutants") and those for which adverse effects on public health have not been demonstrated ("welfare-related pollutants"). In general, the significance of the distinction is that states have more flexibility in establishing plans for the control of welfare-related pollutants than is provided for plans involving health-related pollutants.

In determining whether a designated pollutant is health-related or welfare-related for purposes of section 111(d), the Administrator considers such factors as: (1) known and suspected effects of the pollutant on public health and welfare; (2) potential ambient concentrations of the pollutant; (3) generation of any secondary pollutants for which the designated pollutant may be a precursor; (4) any synergistic effect with other pollutants; and (5) potential effects from accumulation in the environment (e.g., soil, water, and food chains).

It should be noted that the Administrator's determination of whether a designated pollutant is health-related or welfare-related for purposes of section 111(d) does not affect the degree of control represented by EPA's emission guidelines. For reasons discussed in the preamble to Subpart B, EPA's emission guidelines [like standards of performance for new sources under section 111(b)] are based on the degree of control achievable with the best adequately demonstrated control systems (considering costs), rather than on direct protection of public health or welfare. This is true whether a particular designated pollutant has been found to be health-related or welfare-related. Thus, the only consequence of that finding is the degree of flexibility that will be available to the states in establishing plans for control of the pollutant, as indicated above.

Very little information is available on the effects of the total reduced sulfur compounds discharged from kraft pulp mills on human health, animals, vegetation, and materials. Almost all the information that was found during this investigation deals with only hydrogen sulfide (H_2S). Essentially no information on the health and welfare effects of the other reduced sulfur compounds (methyl mercaptan, dimethyl sulfide, and dimethyl disulfide) emitted from kraft pulp mills was found. Therefore, this chapter discusses the effects of hydrogen sulfide only. However, hydrogen sulfide is the predominant TRS compound emitted by kraft pulp mills.

2.2 EFFECTS OF ATMOSPHERIC TRS ON HUMAN HEALTH[1]

At sufficiently high concentrations, hydrogen sulfide is very toxic to humans. It generally enters the human body through the respiratory tract, from which it is carried by the blood stream to various body organs. Hydrogen sulfide that enters the blood can lead to blocking of oxygen transfer, especially at high concentrations. In general, the hydrogen sulfide acts as a cell and enzyme poison and can cause irreversible changes in nerve tissue.

Some of the effects of hydrogen sulfide and the air concentrations at which they occur are shown in Table 2-1. At high concentrations

Table 2-1

EFFECTS OF HYDROGEN SULFIDE INHALATION ON HUMANS

Hydrogen Sulfide Concentration, μg/m^3 (ppm)	Effects
1-45 (7.2×10^{-4} - 3.2×10^{-2})	Odor threshold. No reported injury to health
10 (7.2×10^{-3})	Threshold of reflex effect on eye sensitivity to light
150 (0.10)	Smell slightly perceptible
500 (0.40)	Smell definitely perceptible
15,000 (10.0)	Minimum concentration causing eye irritation
30,000 (20.0)	Maximum allowable occupational exposure for 8 hours (ACGIH Tolerance Limit)
30,000-60,000 (20.0-40.0)	Strongly perceptible but not intolerable smell. Minimum concentration causing lung irritation
150,000 (110)	Olfactory fatigue in 2-15 minutes; irritation of eyes and respiratory tract after 1 hour; death in 8 to 48 hrs
270,000-480,000 (200-350)	No serious damage for 1 hour but intense local irritation; eye irritation in 6 to 8 minutes
640,000-1,120,000 (460-810)	Dangerous concentration after 30 minutes or less
900,000 (650)	Fatal in 30 minutes
1,160,000-1,370,000 (840-990)	Rapid unconsciousness, respiration arrest, and death, possibly without odor sensation
1,500,000+ (1100+)	Immediate unconsciousness and rapid death

(over 1,000,000 $\mu g/m^3$), hydrogen sulfide can cause death quickly by paralysis of the respiratory center. However, if the victim is moved quickly to uncontaminated air and respiration is initiated before heart action stops, rapid recovery can be expected. At lower concentrations (30,000 to 500,000 $\mu g/m^3$), hydrogen sulfide causes conjunctivitis, lachrymal secretion, respiratory tract irritation, pulmonary edema, damage to the heart muscle, psychic changes, disturbed equilibrium, nerve paralysis, spasms, unconsciousness, and circulatory collapse. Some common symptoms are metallic taste, fatigue, diarrhea, blurred vision, intense aching of the eyes, insomnia, and vertigo.

The Occupational Safety and Health Administration (OSHA) has established a maximum allowable exposure concentration (not to be exceeded at any time) for hydrogen sulfide of 30,000 $\mu g/m^3$ (20 ppm). In comparison, OSHA has set a maximum allowable exposure concentration for methyl mercaptans of only 15,000 $\mu g/m^3$ (10 ppm).

Concentrations of TRS as high as 30,000 $\mu g/m^3$ (20 ppm) are not likely to be realized near existing kraft pulp mills. For example, measurements of ambient hydrogen sulfide concentration were made during a six-month period in 1961 and 1962 in the Lewiston, Idaho, area where the major contributor of gaseous pollutants was a pulp mill which had only the recovery furnace controlled for TRS emissions. The levels of hydrogen sulfide were generally less than 15 $\mu g/m^3$. During an air pollution episode in November 1961, peak 2-hour concentrations of 77 $\mu g/m^3$ were measured. These levels are well below the maximum allowable occupational exposure concentration established by OSHA.

For the purpose of evaluating the air pollution impacts associated with alternative emission limits (see Chapter 9), dispersion studies were performed by EPA on model kraft pulp mills. These studies indicated that the maximum ground-level ambient concentration of hydrogen sulfide resulting from an uncontrolled large sized (907 megagrams/day) kraft pulp mill would be about 10,300 $\mu g/m^3$ (one-hour average). This level, even though much higher than actually measured at the existing mill mentioned above, is still lower than the minimum exposure concentration that causes eye irritation.

2.2.1 Odor Perception

The odor characteristic of kraft mills is principally due to the presence of a mixture of hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide. These sulfides are extremely odorous and are detectable at concentrations as low as 1 part per billion (ppb). However, the odor perception thresholds of these gases vary considerably among individuals and apparently depend on the age and sex of the individuals, the size of the town where they live, and whether they smoke. The reported odor threshold of hydrogen sulfide varies between 1 and 45 $\mu g/m^3$ (see Table 2-2). The odor becomes more intense as the concentration increases. At very high concentrations (H_2S above 320,000 $\mu g/m^3$), the smell is not as pungent, probably due to paralysis of the olfactory nerves. At hydrogen sulfide concentrations over 1,120,000 $\mu g/m^3$, there is little sensation of odor and death can occur rapidly. Therefore, this dulling of the sense of smell constitutes a major danger to persons potentially exposed to high concentrations of hydrogen sulfide. The reported odor thresholds for methyl mercaptan, dimethyl sulfide, and dimethyl disulfide are shown in Table 2-3.

Table 2-2

ODOR DETECTION THRESHOLD FOR HYDROGEN SULFIDE [2]

$\mu g/m^3$	(ppmv)
9-45	(.007-.032)
7.1[a]	(.005)
.71[b]	(.0005)
15	(.011)
6.8[c]	(.005)
12-30	(.009-.022)

[a] Hydrogen sulfide from sodium sulfide.

[b] Hydrogen sulfide gas.

[c] Mean value ratio of highest to lowest odor threshold concentration detected by all observers in successive tests is 3.18.

Table 2-3. ODOR THRESHOLDS OF REDUCED SULFUR COMPOUNDS OTHER THAN HYDROGEN SULFIDE [3, 4]

Compound	Odor threshold	
	ppm	$\mu g/m^3$
Methyl Mercaptan-CH_3SH	0.0021	4.5
Dimethyl Sulfide-$(CH_3)_2S$	0.0010	2.9
Dimethyl Disulfide-$(CH_3)_2S_2$	0.0056	23.7

At the ambient ground-level concentrations likely to occur near an uncontrolled kraft pulp mill, as determined by EPA dispersion estimates, odors would definitely be perceptible. A kraft pulp mill that operates typical controls (see Chapter 5) would likely have an odor level that is slightly perceptible.

Most studies dealing with health effects of kraft pulp mill odors are inconclusive. The studies show that populations in the area of an uncontrolled kraft pulp mill are annoyed by the odor, and that short-term effects (vomiting, headaches, shortness of breath, dizziness) occur in some individuals after prolonged exposure. These effects have been reported to be of a psychosomatic nature;[5] however, the evidence in this regard is not conclusive.[6] Studies indicate that the sense of smell becomes rapidly fatigued in the presence of H_2S at levels above the odor threshold.[7] This olfactory fatigue prevents the odor from being perceived over the long term. When perception of the odor becomes weaker or disappears, the effects of the odor also cease.[8]

2.3 EFFECTS OF ATMOSPHERIC TRS ON ANIMALS[9]

Hydrogen sulfide produces about the same health effects in domestic animals as in man, at approximately the same air concentrations. The Air Pollution Control Association Committee on Ambient Air Standards stated that spontaneous injury to animals occurs at 150,000 to 450,000 $\mu g/m^3$ of hydrogen sulfide. These concentrations are, however, much higher than are expected to result from existing kraft pulp mill operation.

2.4 EFFECTS OF ATMOSPHERIC TRS ON VEGETATION[10]

There is little evidence that hydrogen sulfide causes significant injury to field crops at environmental air conditions.

Experiments have indicated that little or no injury occurred to 29 species of plants when they were fumigated with less than 60,000 $\mu g/m^3$ of hydrogen sulfide for five hours. After five hours at 600,000 $\mu g/m^3$, some species were injured, but not all. Boston Fern, apple, cherry, peach and coleus showed appreciable injury at concentrations of 600,000 $\mu g/m^3$. At concentrations between 60,000 and 600,000 $\mu g/m^3$, gladiolus, rose, castor bean, sunflower, and buckwheat showed moderate injury. Tobacco, cucumber, salvia, and tomato were slightly more sensitive.

In general, hydrogen sulfide injures the youngest plant leaves rather than the middle-aged or older ones. Young, rapidly elongating tissues are the most severely injured. Typical exterior symptoms are wilting without typical discoloration (which starts at the tip of the leaf). The scorching of the youngest leaves of the plant occurs first.

2.5 WELFARE EFFECTS OF ATMOSPHERIC TRS

2.5.1 Effect on Property Values[11,12]

Sociologically, such noxious odors can ruin personal and community pride, interfere with human relations in various ways, discourage capital improvements, lower socioeconomic status, and damage a community's reputation. Economically, they can stifle growth and development of a community. Both industry and labor prefer to locate in a desirable area in which to live, work, and play; and the natural tendency is to avoid communities with obvious odor problems. Tourists also shun such areas. The resulting decline in property values, tax revenues, payrolls, and sales can be disastrous to a community.

In summary, the presence of odors may reduce the value of property within the affected area, depending upon the extent to which the odors are considered objectionable to the buyer and seller of the property.

2.5.2 Effects on Paint[13]

Hydrogen sulfide in the atmosphere reacts with paint containing heavy metal salts in the pigment and the drier to form a precipitate which darkens or discolors the surface. Lead, mercury, cobalt, iron, and tin salts cause a gray or black discoloration; cadmium salts cause a yellowish-orange discoloration. Damage to house paint caused by hydrogen sulfide emissions from a kraft pulp mill has been reported in the communities of Lewiston, Idaho, and Clarkston, Washington.[14]

Lead is probably the most common metal to exhibit discoloration caused by the formation of black lead sulfides. The most commonly used white pigment in the past was basic lead carbonate. Titanium dioxide pigments have now generally replaced the use of lead carbonate in the paint industry. However, lead pigments continue to be used in the area of road coatings because of the added durability they impart to paint films.

Experiments have shown that old lead-base paints are more susceptible to hydrogen sulfide damage than are new ones. These experiments have also shown that darkening is dependent on duration of exposure and concentration, and can occur after exposure to hydrogen sulfide concentrations as low as 75 $\mu g/m^3$ for two hours. These experiments indicate that paint darkening by hydrogen sulfide depends on: (1) heavy metal content of paint; (2) temperature and moisture; (3) hydrogen sulfide concentration; (4) age and condition of paint; and (5) presence of other contaminants in the air.

2.5.3 Effects on Metals[15]

Copper and silver can tarnish rapidly in the presence of hydrogen sulfide. However, copper that has been exposed to unpolluted air for some time resists attack by hydrogen sulfide. Experiments have indicated that hydrogen sulfide-sensitive metals, such as silver and copper, will tarnish when exposed to hydrogen sulfide concentrations above 4 μg/m^3 for 40 hours at room temperature. Both moisture and oxygen must be present for tarnishing to occur. The sulfide coating formed on copper and silver electrical contacts can increase resistance when the contacts are closed. In some cases, this can result in the contacts becoming welded shut.

Some alloys of gold, even such a high-carat alloy as 69 percent gold, 25 percent silver and 6 percent platinum, will tarnish when exposed to hydrogen sulfide. However, gold (14-carat and above) and gold leaf (95 percent gold and above) usually will not tarnish appreciably from exposure to atmospheric hydrogen sulfide.

Hydrogen sulfide will attack zinc at room temperature. A zinc sulfide film is formed which prevents further corrosion. At high temperatures, the attack is quite vigorous. At concentrations normally found in the atmosphere and at ambient temperatures, hydrogen sulfide is not corrosive to ferrous metals.

2.6 RATIONALE

Based upon the information provided in the preceding sections of Chapter 2, is it clear that TRS emissions from kraft pulp mills have no significant effect on human health. TRS emissions, however, are highly odorous and studies show that the population in the area of an existing kraft pulp mill is annoyed by the odor. Hydrogen sulfide also has effects on paints and metals at concentrations that can occur in the vicinity of existing kraft pulp mills. The Administrator has concluded that TRS emissions from kraft pulp mills do not contribute to the endangerment of public health. Thus, TRS emissions will be considered a welfare-related pollutant for purposes of Section 111(d) and Subpart B of Part 60.

REFERENCES FOR CHAPTER 2

1. Preliminary Air Pollution Survey of Hydrogen Sulfide, A Literature Review. U. S. Department of Health, Education, and Welfare. October 1969. pp 2-4; 29-32.

2. Op Cit, Reference 1. Table 1.

3. Adams, D. F., and F. A. Young. Kraft Odor Detection and Objectionability Thresholds. Washington State University Progress Report on U. S. Public Health Service Grant. 1965.

4. Leonardos, G., et al. Odor Threshold Determinations of 53 Odorant Chemicals. Presented at 61st Annual Meeting of the Air Pollution Control Association. St. Paul, Minnesota. June 1968.

5. Pavanello, R., and D. Rondia. "Odor Nuisance and Public Health, Part 2". Water Waste Treatment. June 1971.

6. Hydrogen Sulfide Health Effects and Recommended Air Quality Standard. Illinois Institute for Environmental Quality. PB-233-843. March 1974.

7. Sullivan, R. J. Preliminary Air Pollution Survey of Odorous Compounds. Department of Health, Education, and Welfare. Raleigh, North Carolina. APTD 69-42. October 1969. pp 8-9.

8. Op Cit, Reference 6. pp 17-22.

9. Op Cit, Reference 1. pp 6-7.

10. Op Cit, Reference 1. p 12.

11. Op Cit, Reference 7. pp 1-2.

12. A Study of the Social and Economic Impact of Odors. Copley International Corporation. EPA Contract No. 68-02-0095. February 1973.

13. Op Cit, Reference 1. pp 16-19.

14. "A Study of Air Pollution in the Interstate Region of Lewiston, Idaho, and Clarkston, Washington". Public Health Service Publication 999-AP-8. 1964.

15. Op Cit, Reference 1. pp 19-20.

3. INDUSTRY CHARACTERIZATION

3.1 Geographic Distribution

As of December 1975, there were 56 firms operating about 120 kraft pulping mills in 28 states. Most U.S. kraft pulping mills and mill capacity is found in the South. Alabama, Georgia, and Louisiana are the leaders. Alabama has 13 mills and 10 percent of U.S. mill capacity. Georgia has 11 mills and 13 percent of U.S. mill capacity. And Louisiana has 11 mills and 11 percent of U.S. capacity. Over the past 20 years, growth in the kraft pulping industry has occurred mainly in the South.[1] However, recent and planned modifications to existing mills as well as plans for new mills are found in all sections of the country.[2]

3.2 Integration and Concentration

Only about 1/3 of the 56 firms are producers of pulp, paper, and/or paperboard exclusively. The others are engaged in a wide variety of activities. The activities include chemical manufacture, detergent production, magazine publishing, land development, and can production. The degree of dependency on kraft pulping and related activities varies anong these horizontally integrated firms. Whereas International Paper Company derived 55.6 percent of their 1974 sales from pulp, paper, and paperboard production,Ethyl Corporation derived 11 percent of 1974 sales from pulp and paper operations.

Besides being horizontally integrated, the U.S. kraft pulping industry is highly concentrated. The 6 largest firms in terms of mill capacity account for 40 percent of U.S. kraft pulp capacity. The 10 largest account for 56 percent of U.S. kraft pulp capacity.

Vertical integration is another characteristic of the U.S. kraft pulping industry. Only 41 U.S. kraft pulping mills are listed in the directory of world market pulp producers. The most prevalent kraft grade listed is bleached hardwood followed closely by bleached softwood. Moreover, appearance in the directory does not mean the mills' pulp cannot be used captively. When available, pulp for market is produced at the designated mills. However, nearly all kraft pulp (about 90 percent) produced in the U.S. is not marketed but is used captively.[3] In fact, 109 kraft pulping mills also have facilities at the same location for producing paper and paperboard. However, these mills cannot always satisfy the kraft pulping requirements of the paper and paperboard facilities. Oftentimes, intracompany transfers from other U.S. and Canadian mills are required to fill the kraft pulping voids.

3.3 International Influence

The U.S. kraft pulping industry is not devoid of foreign influence. Pulp, paper, and paperboard production in other countries, especially Canada, has a pronounced influence on U.S. kraft pulping firms and trade balances. Although the U.S. is the world's largest producer of kraft pulp and the fourth leading exporter (behind Canada, Sweden, and Finland), the U.S. has been a net importer of kraft pulp. Over 90 percent of the kraft pulp imported to the U.S. comes from Canada. This is not surprising in view of the earlier statement about intracompany transfers and the fact that a third of the U.S. kraft pulp producers have kraft pulping facilities in Canada.

The aforementioned industry characterization statements were derived primarily from Appendix A and Tables 3-1 and 3-2. Appendix A displays

Table 3-1. SUMMARY INDUSTRY STATISTICS: FIRMS-MILL NUMBER AND CAPACITY DISTRIBUTION

Firm	# U.S. Mills	% U.S. Total	Capacity U.S. Mills Megagram Per Day	Capacity U.S. Mills Tons Per Day	% of U.S. Total
Allied Paper, Inc. (sub. of SCM)	1	1	445	(490)	<1
Alton Box Board Co.	1	1	590	(650)	<1
American Can Co.	2	2	1,125	(1,240)	1
Appleton Papers, Inc. (Div. of NCR)	1	1	163	(180)	negligible
Boise Cascade Corp.	5	4	3,438	(3,790)	4
Bowater, Inc.	2	2	1,360	(1,500)	1
Brown Co.	1	1	635	(700)	<1
Champion International	3	3	2,430	(2,680)	3
Chesapeake Corp. of Va.	1	1	1,043	(1,150)	1
Consolidated Papers, Inc.	1	1	358	(395)	negligible
Container Corp. of Amer. (sub. of Marcor)	2	2	2,040	(2,250)	2
Continental Can Co.	4	3	3,355	(3,700)	4
Crown Zellerbach	5.5	5	3,824	(4,216)	4
Diamond Int'l Corp.	1	1	385	(425)	negligible
Federal Paper Board Co., Inc.	1	1	1,088	(1,200)	1
Fibreboard Corp.	1	1	408	(450)	negligible
Georgia-Pacific Corp.	4	3	5,007	(5,520)	5
Gilman Paper Co.	1	1	998	(1,100)	1
P.H. Glatfelter Co.	1	1	454	(500)	negligible
Great Northern Nekoosa Corp.	3	3	2,276	(2,510)	2
Green Bay Packaging, Inc.	1	1	590	(650)	<1
Gulf States Paper Corp.	2	2	794	(875)	<1
Hammermill Paper Co.	2	2	777	(856)	<1
Hoerner Waldorf Corp.	2	2	1,950	(2,150)	2
Hudson Paper Co.	1	1	861	(950)	<1
ITT Rayonier, Inc.	1	1	1,133	(1,250)	1
Inland Container Corp.	1.5	1	1,100	(1,213)	1

Table 3-1 (Continued). SUMMARY INDUSTRY STATISTICS: FIRMS-MILL NUMBER AND CAPACITY DISTRIBUTION

			Capacity U.S. Mills		
Firm	# U.S. Mills	% U.S. Total	Megagram Per Day	Tons Per Day	% of U.S. Total
International Paper Co.	14	12	14,500	(15,985)	14
Interstate Container Corp.	1	1	500	(550)	<1
Kemberly-Clark Corp.	1	1	530	(585)	<1
Lincoln Pulp & Paper Co. (Div. of Premoid)	1	1	290	(320)	<1
Longview Fibre Co.	1	1	1,723	(1,900)	1
Louisiana Pacific Corp.	1	1	635	(700)	<1
MacMillan Bloedel Ltd.	1	1	840	(925)	<1
Mead Corp.	4	3	2,837	(3,128)	4
Mosinee Paper Corp.	1	1	160	(175)	<1
Olin Kraft, Inc.	1	1	1,043	(1,150)	1
Owens-Illinois, Inc.	2	2	1,610	(1,775)	2
Oxford Paper (Div. Ethyl Corp.)	1	1	530	(585)	<1
Packaging Corp. of Amer. (A Tenneco Co.)	1	1	703	(775)	<1
Penntech Papers, Inc.	1	1	163	(180)	negligible
Pineville Kraft Corp.	1	1	800	(880)	<1
Potlatch Corp.	2	2	1,225	(1,350)	1
Procter & Gamble Co.	1	1	816	(900)	<1
St. Joe Paper Co.	1	1	1,180	(1,300)	1
St. Regis Paper Co.	4	3	4,880	(5,381)	5
Scott Paper Co.	3.5	3	2,450	(2,700)	3
Simpson Lee Paper Co.	1.5	1	690	(760)	<1
Southland Paper Mills, Inc.	2	2	816	(900)	<1
Southwest Forest Industries	1	1	545	(600)	<1
South Carolina Industries (79% owned by Stone Container Corp.)	1	1	612	(675)	<1
Temple-Eastex, Inc. (sub. of Time, Inc.)	1	1	1,180	(1,300)	1
Union Camp Corp.	3	3	4,517	(4,980)	5
Western Kraft	3	3	1,243	(1,370)	1
Westvaco Corp.	4	3	3,858	(4,254)	5
Weyerhauser Co.	7	6	5,620	(6,195)	6
Totals 56	119		95,750	(105,567)	

Table 3-2. SUMMARY INDUSTRY STATISTICS: STATES-MILL NUMBER AND CAPACITY DISTRIBUTION

State	Number of Mills	% of U.S. Total	State Mill Capacity Megagram Per Day	State Mill Capacity Tons Per Day	% of U.S. Total
Alabama	13	11	9,325	(10,280)	10
Arizona	1	1	545	(600)	1
Arkansas	6	5	4,925	(5,430)	5
California	4	3	1,732	(1,910)	2
Florida	8	7	8,400	(9,260)	9
Georgia	11	9	12,250	(13,505)	13
Idaho	1	1	860	(950)	1
Kentucky	2	2	835	(920)	1
Louisiana	11	9	10,570	(11,655)	11
Maine	6	5	3,583	(3,950)	4
Maryland	1	1	603	(665)	1
Michigan	2	2	750	(825)	1
Minnesota	2	2	785	(865)	1
Mississippi	4	3	4,270	(4,707)	4
Montana	1	1	1,090	(1,200)	1
New Hampshire	1	1	635	(700)	1
New York	1	1	535	(590)	1
North Carolina	5	4	5,125	(5,650)	5
Ohio	1	1	490	(540)	1
Oklahoma	1	1	1,450	(1,600)	2
Oregon	7	6	5,357	(5,906)	6
Pennsylvania	3	3	780	(860)	1
South Carolina	4	3	4,983	(5,494)	5
Tennessee	2	2	1,156	(1,275)	1
Texas	6	5	4,145	(4,570)	4
Virginia	4	3	4,127	(4,550)	4
Washington	7	6	5,310	(5,854)	6
Wisconsin	4	3	1,140	(1,256)	1
Totals 28	119		95,750	(105,567)	

kraft mill characteristics. Table 3-1 exhibits mill number and capacity distribution by firm. Table 3-2 exhibits mill number and capacity distribution by state.

REFERENCES FOR CHAPTER 3

1. Guthrie, John A. An Economic Analysis of the Pulp and Paper Industry. Pullman, Washington, Washington State University Press, 1972, pp. 1-15.
2. Van Derveer, Paul D. Profiles of the North American Pulp and Paper Industry. Pulp & Paper. June 30, 1975. pp. 32-33; 36-38; 43-44; 48-49.
3. Wood Pulp Statistics 36th Edition. Pulp & Raw Materials Group, New York, American Paper Institute, Inc., October 1972. pp. 63-83.

4. PROCESS DESCRIPTION

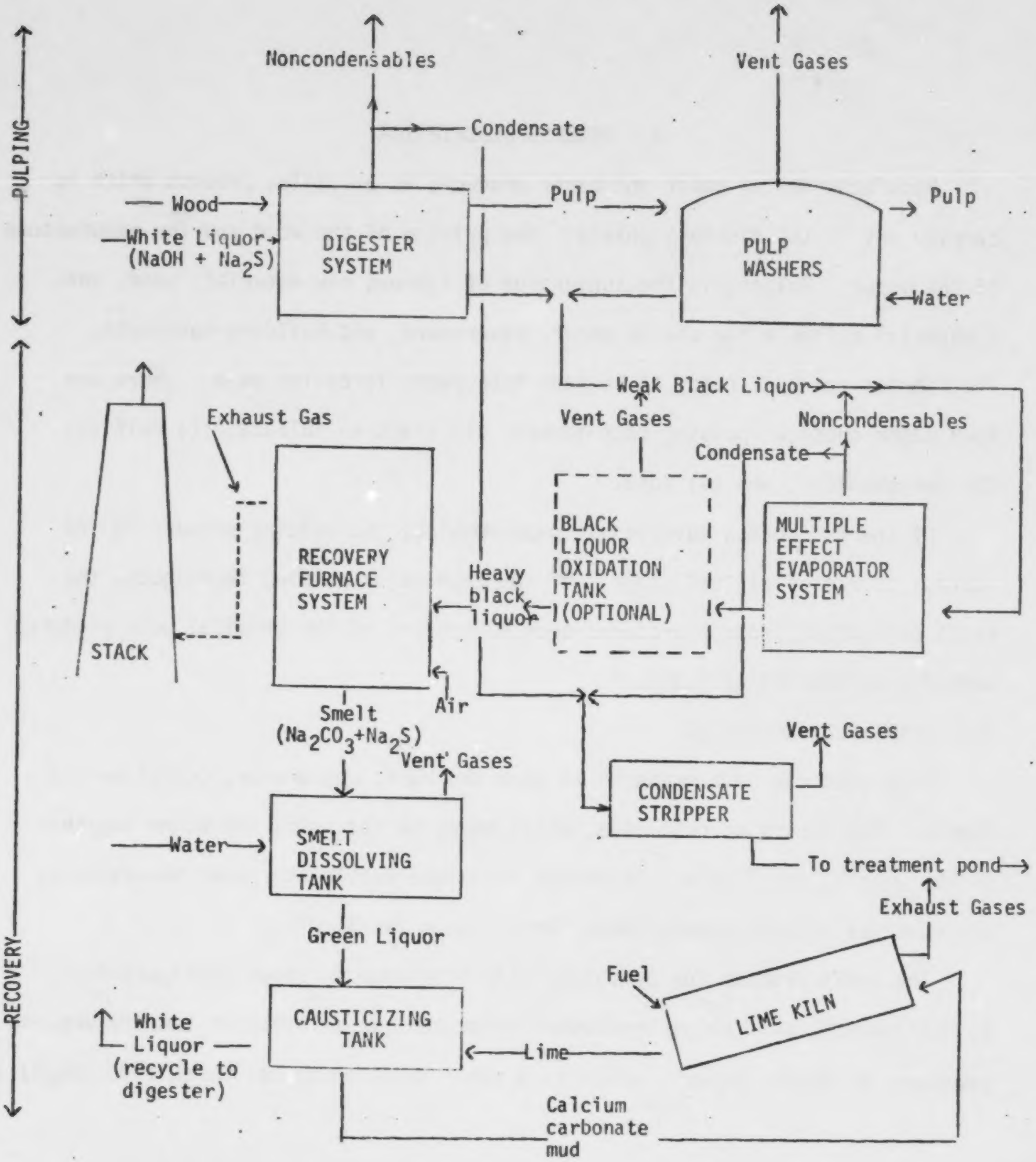
Manufacturing of paper and paper products is a complex process which is carried out in two distinct phases: the pulping of the wood and the manufacture of the paper. Pulping is the conversion of fibrous raw material, wood, into a material suitable for use in paper, paperboard, and building materials. The fibrous material ready to be made into paper is called pulp. There are four major chemical pulping techniques: (1) kraft or sulfate, (2) sulfite, (3) semichemical, and (4) soda.

Of the two phases involved in paper-making, the pulping process is the largest source of air pollution. Of the four major pulping techniques, the kraft or sulfate process produces over 80 percent of the chemical pulp produced annually in the United States.[1]

4.1 KRAFT PULPING PROCESS

Pulp wood can be considered to have two basic components, cellulose and lignin. The fibers of cellulose, which comprise the pulp, are bound together in the wood by the lignin. To render cellulose usable for paper manufacture, any chemical pulping process must first remove the lignin.

The kraft process for producing pulp from wood is shown in Figure 4-1. In the process, wood chips are cooked (digested) at an elevated temperature and pressure in "white liquor", which is a water solution of sodium sulfide (Na_2S) and



PULPING
RECOVERY
Noncondensables
Condensate
Vent Gases
Wood
White Liquor (NaOH + Na_2S)
DIGESTER SYSTEM
Pulp
PULP WASHERS
Pulp
Water
Weak Black Liquor
Vent Gases
Noncondensables
Condensate
Exhaust Gas
RECOVERY FURNACE SYSTEM
Heavy black liquor
BLACK LIQUOR OXIDATION TANK (OPTIONAL)
MULTIPLE EFFECT EVAPORATOR SYSTEM
STACK
Air
Smelt (Na_2CO_3+Na_2S)
Vent Gases
Vent Gases
CONDENSATE STRIPPER
Water
SMELT DISSOLVING TANK
To treatment pond
Exhaust Gases
Green Liquor
Fuel
LIME KILN
White Liquor (recycle to digester)
CAUSTICIZING TANK
Lime
Calcium carbonate mud

Figure 4-1. KRAFT PULPING PROCESS

sodium hydroxide (NaOH). The white liquor chemically dissolves lignin from the wood. The remaining cellulose (pulp) is filtered from the spent cooking liquor and washed with water. Usually, the pulp then proceeds through various intermittent stages of washing and possibly bleaching, after which it is pressed and dried into the finished product (paper).

The balance of the process is designed to recover the cooking chemicals and heat. Spent cooking liquor and the pulp wash water are combined to form a weak black liquor which is concentrated in a multiple-effect evaporator system to about 55 percent solids. The black liquor can then be further concentrated to 65 percent solids in a direct-contact evaporator, which evaporates water by bringing the liquor in contact with the flue gases from a recovery furnace, or in an indirect-contact evaporator. The strong black liquor is then fired in a recovery furnace. Combustion of the organics dissolved in the black liquor provides heat for generating process steam and converting sodium sulfate (Na_2SO_4) to Na_2S. To make up for chemicals lost in the operating cycle, salt cake (sodium sulfate) is usually added to the concentrated black liquor before it is sprayed into the furnace. Inorganic chemicals present in the black liquor collect as a molten smelt at the bottom of the furnace.

The smelt, consisting of sodium carbonate (Na_2CO_3) and sodium sulfide, is dissolved in water to form green liquor which is transferred to a causticizing tank where quicklime (CaO) is added to convert the sodium carbonate to sodium hydroxide. Formation of the sodium hydroxide completes the regeneration of white liquor, which is returned to the digester system. A calcium carbonate mud precipitates from the causticizing tank and is calcined in a lime kiln to regenerate quicklime.

4.2 DESCRIPTION OF INDIVIDUAL PROCESS FACILITIES

4.2.1 Digester System

Wood chips are cooked with white liquor at about 170 to 175°C and at pressures ranging from 6.9 to 9.3 x 10^5 pascals (100 to 135 psig). Gases formed during digestion are vented to "relieve" the digester and maintain proper cooking pressure. At some mills the gases are first cooled to condense and recover turpentine before venting. The condenser cooling water recovers the heat and may be used in some other process. There are two types of digester system: batch and continuous. At the end of the cooking cycle in a batch digester system, the contents of the digester are transferred to an atmospheric tank usually referred to as a blow tank. Here the major portion of the spent cooking liquor containing the dissolved lignin is drained and the pulp is transferred to the initial stage of washing. Steam and other gases that flash from the blow tank are piped to a heat recovery unit. This blow of the digester is not applicable to continuous digester systems. Most kraft pulping is presently done in batch digesters, although increasing numbers of continuous digesters are being employed in the industry.

4.2.2 Brown Stock Washer System

Pulp from the digester system normally passes through the knotter which removes chunks of wood not digested during cooking. The pulp then is washed countercurrently with water in several sequential stages. On leaving each stage, the pulp is dewatered on a vacuum filter, and the water drains into filtrate tanks. The washers are normally hooded to collect the vapors that steam off the open washers.

4.2.3 Multiple-Effect Evaporator System

Spent cooking liquor from the digester system is combined with the brown stock washer discharge to form weak (dilute) black liquor. Multiple-effect evaporators are utilized to concentrate the weak black liquor from an initial 12 to 18 percent solids to a final level of 40 to 55 percent solids. Usually, five or six evaporation units (effects) make up the system. Each effect consists of a vapor head and a heating element. Hot vapors from the vapor head of a previous effect pass to the heating element of the following effect. The effects are operated at successively lower pressures, which causes a decrease in the boiling point of the liquor. Vapors after the final effect are condensed rapidly enough to maintain a high vacuum. Two types of barometric condensers are used: direct contact condensers and surface condensers. Each type of condenser is equipped with a steam ejector to remove noncondensables.

4.2.4 Recovery Furnace System

The purposes of burning concentrated black liquor in the kraft recovery furnace are: (a) to recover sodium and sulfur, (b) to produce steam, and (c) to dispose of unwanted dissolved wood components in the liquor. In most instances, liquor of 60 to 65 percent solids content will burn in a self-supporting combustion.

The recovery furnace theoretically is divided into three sections: the drying zone, the reducing zone, and the oxidizing zone. The black liquor is introduced to the furnace through spray guns located in the drying zone. The heat in the furnace is sufficient to evaporate the remaining water from the liquor. The dried solids fall to the hearth to form the char bed.

Combustion of the black liquor char begins on the hearth of the furnace. Air for combustion is supplied by a forced-draft system to the reducing and oxidizing zone of the furnace. Since a reducing atmosphere is required to convert sodium sulfate and other sodium-base sulfur compounds to sodium sulfide, only a portion of the air required for complete combustion is supplied to the char bed through the lower or primary air ports. The heat released by the combustion in the zone is sufficient to liquefy the chemicals in the char and to sustain the endothermic reduction. The liquefied chemical, or molten smelt, is continuously drained from the furnace hearth.

Air is admitted through secondary and tertiary air ports above the primary zone to complete the combustion of the volatile gases from the char in the furnace.

There are two main types of recovery furnace systems. The first type employs a direct-contact evaporator to provide the final stage of evaporation for the black liquor. This is accomplished by bringing the black liquor in direct contact with the furnace's exhaust gases. This furnace type is called a conventional or direct-contact system. A conventional system is shown in Figure 4-2. The second type of recovery furnace system employs an indirect-contact evaporator as the final evaporation stage; this type is called a noncontact direct-fired, or "low odor" system. A noncontact system is shown in Figure 4-3. The majority of the furnace systems in operation are the conventional type.

In addition, so-called cross-recovery is practiced at several mills. This practice is where the waste liquor from neutral sulfite semi-chemical (NSSC) cooking is combined with the black liquor from the kraft mill prior to burning. The inorganic content of the NSSC liquor will join the bulk of inorganics and occur in the smelt from the furnace, substituting for the sodium sulfate normally added in the kraft recovery cycle to cover losses of chemicals.

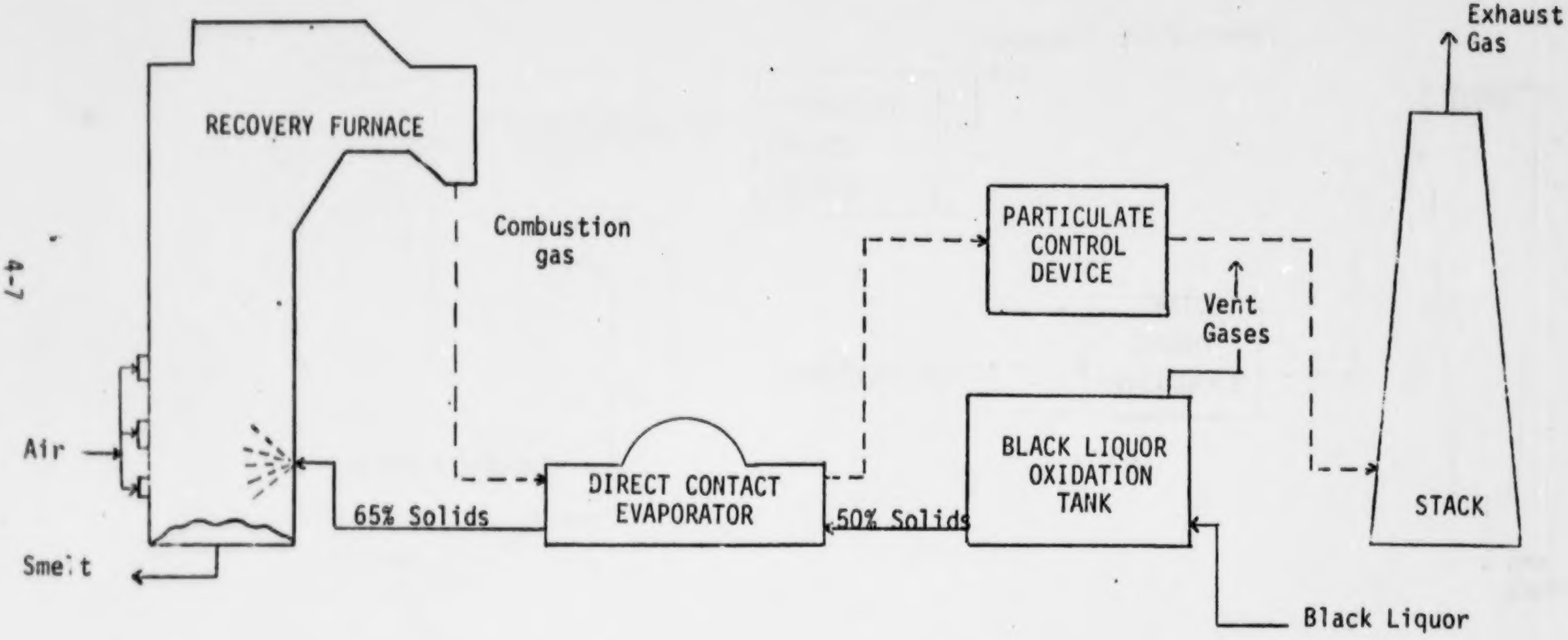

RECOVERY FURNACE
Combustion gas
Air
Smelt
65% Solids
DIRECT CONTACT EVAPORATOR
50% Solids
PARTICULATE CONTROL DEVICE
Vent Gases
BLACK LIQUOR OXIDATION TANK
Black Liquor
STACK
Exhaust Gas

Figure 4-2. Direct Contact (Conventional) Recovery Furnace System With Black Liquor Oxidation

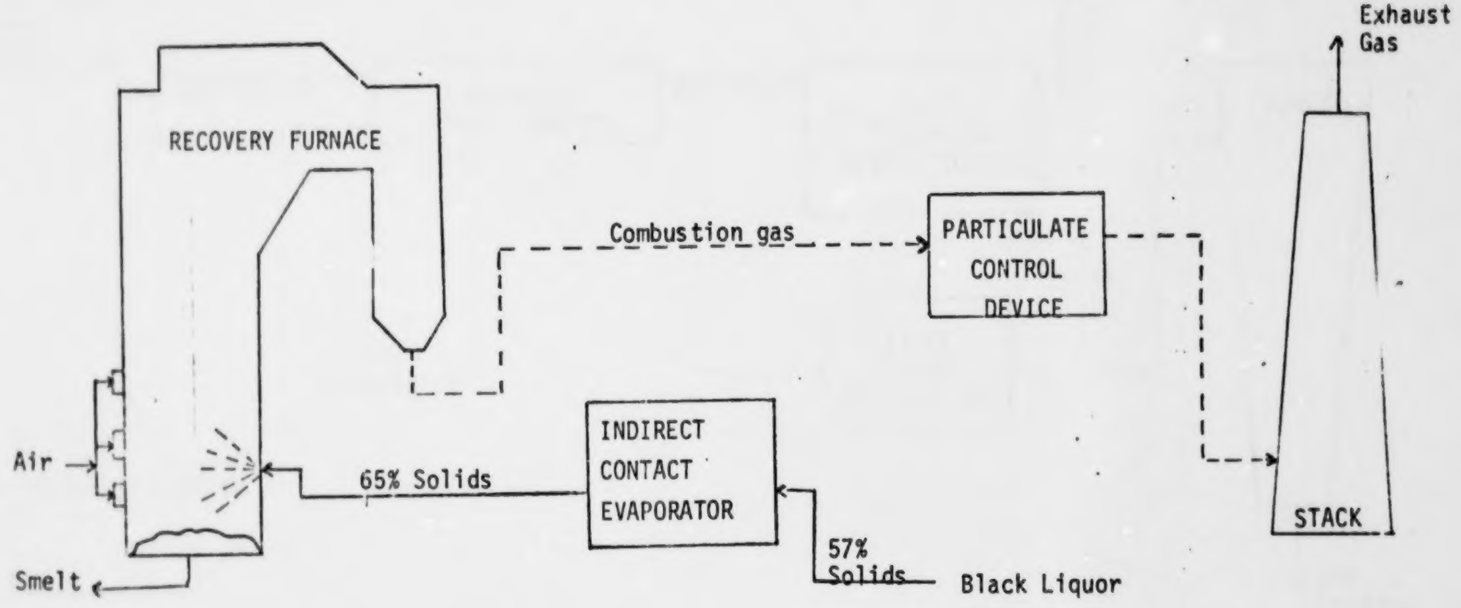

RECOVERY FURNACE
Air
Smelt
65% Solids
Combustion gas
PARTICULATE CONTROL DEVICE
INDIRECT CONTACT EVAPORATOR
57% Solids
Black Liquor
Exhaust Gas
STACK

Figure 4-3. Indirect Contact Recovery Furnace System

4.2.5 Smelt Dissolving Tank

The smelt dissolver is a large tank located below the recovery furnace hearth. Molten smelt (sodium carbonate and sodium sulfide) that accumulates on the floor of the furnace is dissolved in water to form green liquor in the tank. The tank is equipped with an agitator to assist dissolution, and a steam or liquid shatterjet system to break up the smelt stream before it enters the solution. Contact of the molten smelt with the water causes the evolution of large volumes of steam, which must be vented.

The sodium carbonate (Na_2CO_3) in the green liquor is converted to sodium hydroxide (NaOH) in the causticizing tank. This is done by adding quicklime (CaO) to the liquor. The quicklime forms sodium hydroxide, $Ca(OH)_2$, which reacts with Na_2CO_3; calcium carbonate precipitates out and is converted back into quicklime in a lime kiln.

4.2.6 Lime Kiln

The lime kiln is an essential element of the closed-loop system that converts green liquor (solution of sodium carbonate and sodium sulfide) to white liquor. The kiln calcines the lime mud (calcium carbonate which precipitates from the causticizer) to produce calcium oxide (quicklime, CaO). The quicklime is wetted (slaked) by the water in the green liquor solution to form calcium hydroxide, $Ca(OH)_2$, for the causticizing reaction.

The kraft pulp industry typically uses large rotary kilns that are capable of producing 36 to 360 megagrams (40 to 400 tons) of quicklime per day. Lime mud is fed in at the elevated end as a 55 to 60 percent solid-water slurry. The mud is contacted by hot gases produced by the combustion of natural gas or fuel oil and proceeding through the kiln in the opposite direction. Large motors turn the entire kiln at low speeds (1-2 rpm), causing the lime to proceed downward through the kiln toward the high-temperature zone (980 to 1090°C; 1800 to 2000°F) to discharge at the lower end. As the mud moves along, it dries in the upper section, which may be equipped with chains or baffles to give the wet mud better contact with the gases. As the lime mud moves down farther, it agglomerates into small pellets and finally is calcined to calcium oxide in the high-temperature zone near the burner.

Fluidized bed calciners are presently being used at four kraft pulp mills, but the production rate of each kiln at this time is under 136 megagrams (150 tons) of lime per day.

4.2.7 Black Liquor Oxidation System

Black liquor oxidation is the practice of oxidizing the sodium sulfide in either weak or strong black liquor to sodium thiosulfate or possibly higher oxidation states. Black liquor oxidation is designed to decrease the emissions from the direct contact evaporator by producing a negligible sodium sulfide concentration in the black liquor. In those mills which oxidize black liquor, air is most often used. However, molecular oxygen has been used instead of air at two mills. Sparging reactors, packed towers, and bubble tray columns have been used in singular or multiple stages to provide intimate contact between the liquor and air.

air at two mills. Sparging reactors, packed towers, and bubble tray columns
between the liquor and air.

4.2.8 Condensate Stripping System

When digester and multiple-effect evaporator off-gases are condensed, some TRS gases are partially dissolved in the condensate. To prevent the release of kraft odor from the water treatment ponds, the TRS compounds can be stripped from the digester and multiple-effect evaporator condensates prior to being discharged to the ponds. The two principal ways of stripping are air stripping and steam stripping. Stripping can be performed in multistage (multiple tray) columns with a large countercurrent flow of air or steam.

REFERENCES FOR CHAPTER 4

1. *Atmospheric Emissions from the Pulp and Paper Manufacturing Industry*, EPA-450/1-73-002, September 1973, page 5. (Also published by NCASI as Technical Bulletin No. 69, February 1974).

5. EMISSIONS

5.1 NATURE OF EMISSIONS

The characteristic kraft mill odor is caused principally by a variable mixture of hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide. All of these gases contain sulfur, which is a necessary component of the kraft cooking liquor.

Hydrogen sulfide emissions originate from the breakdown of sodium sulfide, which is a component of the kraft cooking liquor. Methyl mercaptan and dimethyl sulfide are formed in reactions with the wood component lignin. Dimethyl disulfide is formed through the oxidation of mercaptan groups derived from the thiolignins.

5.1.1 Hydrogen Sulfide

Hydrogen sulfide (H_2S) is a weak acidic gas which partially ionizes in aqueous solution. The ionization proceeds in two stages with the formation of hydrosulfide and, with increasing pH, sulfide ions

$$H_2S \rightleftarrows HS^- + H^+ \rightleftarrows S^= + 2H^+ \qquad (5\text{-}1)$$

increasing pH →

Black liquor contains a high concentration of dissolved sodium sulfide in strongly alkaline solution. If the pH were depressed, the sodium sulfide would hydrolyze to sodium hydrosulfide. Below pH 8, appreciable unionized hydrogen sulfide would form as the reaction equilibrium in equation 5-1 moves from right to left. It is reported that at a pH of about 8.0, most hydrogen sulfide forms hydrosulfide ions. Consequently, in normal black liquor conditions, there is very little dissolved hydrogen sulfide in the liquor.[1]

Due to the equilibrium between the hydrosulfide ion and water vapor, hydrogen sulfide gas can be stripped from black liquor at steam vents. There could be, therefore, a significant concentration of H_2S in the evaporator areas of the kraft mill.

Hydrogen sulfide is formed in the recovery furnace and lime kiln as the sulfur-containing compounds from the black liquor or lime mud are volatilized and reduced. Hydrogen sulfide generally represents the largest gaseous emission from the kraft process.

5.1.2 Methyl Mercaptan

Methyl mercaptan (MeSH) is a reduced sulfur compound which is formed during the kraft cook by the reaction of hydrosulfide ion and the methoxy-lignin component of the wood:[2]

$$\text{Lignin} - OCH_3 + HS^- \rightarrow \text{MeSH} + \text{Lignin} - O^- \qquad (5\text{-}2)$$

Methyl mercaptan will also dissociate in an aqueous solution to methyl mercaptide ion. It is reported that this dissociation is essentially complete above a pH of 12.0.[3] Methyl mercaptan is, therefore, present in low concentrations as a dissolved gas in the black liquor. As the pH decreases, MeSH gas is evolved.

Methyl mercaptan is primarily emitted from the digester relief and blow where it is formed, and from the brown stock washers where the pH of the liquor drops below the equilibrium point. Emissions decrease as the residual concentration in the liquor diminishes.[4]

5.1.3 Dimethyl Sulfide

Dimethyl Sulfide (MeSMe) is primarily formed through the reaction of methyl mercaptide ion with the methoxy-lignin component of the wood:[2]

$$\text{Lignin} - OCH_3 + MeS^- \rightarrow \text{Lignin} - O^- + MeSMe$$

Dimethyl sulfide may also be formed by the disproportionation of methyl mercaptan. At normal liquor temperature (150-200°F) it is highly volatile. It does not, however, dissociate as hydrogen sulfide and methyl mercaptan do.

5.1.4 Dimethyl Disulfide

Dimethyl disulfide (MeSSMe) is formed by the oxidation of methyl mercaptan throughout the recovery system, especially in oxidation towers:

$$4\ MeSH + O_2 \rightleftarrows 2\ MeSSMe + 2\ H_2O \quad (5\text{-}4)$$

Dimethyl disulfide has a higher boiling point than any of the other compounds and its retention in the liquor is therefore greater.

5.2 UNCONTROLLED TOTAL REDUCED SULFUR EMISSIONS

Uncontrolled total reduced sulfur (TRS) emissions are listed in Table 5-1 for each of the TRS sources under consideration. These emission rates are for a 907 megagrams per day (1000 tons per day) kraft pulp mill. Table 5-1 also lists typical gas volume rates for each source.

5.2.1 Recovery Furnace System

TRS emissions are generated both in the furnace and in the direct-contact evaporator. The furnace-generated TRS concentration is as high as several hundred parts per million (ppm) and as low as 1 ppm depending on the furnace design and operation. Recovery furnace emissions are affected by the relative quantity and distribution of combustion air, rate of solids (concentrated black liquor) feed, spray pattern and droplet size of the liquor fed, turbulence in the oxidation zone, smelt bed disturbance, and the combination of sulfidity and heat content value of the liquor fed. The impact of these variables on TRS emissions is independent of the absence or presence of a direct-contact evaporator.

TRS emissions generated in the direct-contact evaporator depend largely on the concentration of sodium sulfide in the black liquor. Acidic gases such as carbon dioxide in the flue gas can change the black liquor equilibrium, resulting in the release of increased quantities of hydrogen sulfide and methyl mercaptan.

Uncontrolled TRS emissions from a conventional recovery furnace system range from 0.75 to 31 grams per kilogram (1.5 to 62 pounds per ton) of air dried pulp and average about 7.5 grams per kilogram (15 pounds per ton) of air dried pulp (ADP).[6] This is an average of about 550 ppm.

5.2.2 Digester System

The noncondensable gases from the relief system and the blow tank vent contain TRS concentrations as high as 30,000 ppm.[7] Both streams are sometimes referred to as digester "noncondensables". TRS compounds formed in the digester are mainly methyl mercaptan, dimethyl sulfide and dimethyl disulfide. Uncontrolled TRS emissions from a digester system range between 0.24 and 5.25 g/kg ADP (0.47 and 10.5 lb/ton ADP) and average about 0.75 g/kg ADP (1.5 lb/ton ADP) at a concentration of 9,500 ppm.[7] Operating variables that affect digester TRS emissions include the black liquor recycle rate, cook duration, cooking liquor sulfidity (percentage of sodium sulfide to total alkali, Na_2S and NaOH, in white liquor), and residual alkali level.

5.2.3 Multiple-Effect Evaporator System

The noncondensable gases from a multiple-effect evaporator (MEE) system consist of air drawn in through system leaks and reduced sulfur compounds that were either in the dilute black liquor or formed during the evaporation process. TRS emissions from the MEE system are as high as 44,000 ppm.[8] Uncontrolled TRS emissions from a MEE system average about 0.5 g/kg ADP (1.0 lb/T ADP) at a concentration of 6700 ppm.[8]

The type of condenser used can influence the concentration of TRS emissions. Certain types of condensers (e.g. direct-contact) allow the noncondensable gases and the condensate to mix, which results in a limited quantity of hydrogen

Table 5-1. TRS EMISSIONS FROM AN UNCONTROLLED 907 MEGAGRAMS PER DAY (1000 TONS PER DAY) KRAFT PULP MILL(1)

Source	Typical Exhaust Gas Flow Rate m^3/s(acfm)	TRS Emission Range		Average(2) TRS Emission Rate		
		ppm	g/kg ADP (1b/T ADP)	ppm	g/s(1b/hr)	g/kg ADP(1b/T ADP)
Recovery Furnace	212(450,000)	18-1303	0.75-31(1.5-62)	550	79(625)	7.5(15.0)
Digester System	3(6,200)	1525-30,000	0.24-5.3(0.47-10.5)	9,500	8(63)	0.75(1.5)
Multiple-Effect Evaporator System	1(2,200)	92-44,000	0.015-3.2(0.03-6.3)	6,700	5(42)	0.5(1.0)
Lime Kiln	37(79,200)	3-613	0.01-2.1(0.02-4.2)	170	4(33)	0.4(0.8)
Brown Stock Washer System	71(150,000)	-	0.005-0.5(0.01-0.9)	30	2(13)	0.15(0.3)
Black Liquor Oxidation System	14(30,000)	3-335	0.005-0.37(0.01-0.73)	35	0.5(4)	0.05(0.1)
Smelt Dissolving Tank	27(58,100)	5-811	0.007-1.9(0.013-3.70)	60	1(8)	0.1(0.2)
Condensate Stripper System	2(4,000)	-	-	5000	10(83)	1.0(2.0)

(1)Uncontrolled emission data for condensate strippers were obtained from Reference 13. Data for all other sources were obtained from Reference 5.

(2)Average values listed are calculated from data listed in Reference 5. Insufficient information was available in Reference 5 to evaluate the operation of the units for which data were reported.

sulfide and methyl mercaptan gases dissolved in the water. This reduces the TRS concentration from the system, but increases the sulfide level in the condensate. Sulfidity and pH of the weak black liquor also have an effect on the TRS concentration from the multiple-effect evaporators. Higher sulfidity levels result in higher TRS emissions. TRS levels increase with decreasing pH levels.

5.2.4 Lime Kiln

TRS emissions can be generated in the lime kiln proper and in the downstream scrubber which is normally installed to control particulate emissions.

TRS emissions originating in the lime kiln are affected by the oxygen content of the exhaust, the kiln length to diameter ratio, the lime mud sulfide content, cold-end exit gas temperature, and simultaneous burning of sulfur bearing materials contained in the lime mud (e.g., green liquor dregs, the impurities resulting from clarifying the green liquor).[9]

If digester and evaporator condensates are used as lime kiln scrubber water, reduced sulfur compounds can be stripped into the exist gas stream. If the scrubbing liquor contains sodium sulfide, as it does in some installations, H_2S may be released in the scrubber as a result of the equilibrium shift caused by the absorption of CO_2 in the liquor.

Uncontrolled TRS emissions from a lime kiln average about 0.4 g/kg ADP (0.8 lb/T ADP) at a concentration of 170 ppm. TRS emissions from lime kilns range between 3 and 600 ppm (0.02 to 4.2 lb/T ADP) depending on combustion characteristics of the individual kilns.[10]

5.2.5 Brown Stock Washer System

TRS emissions from the brown stock washers arise primarily from the vaporization of the volatile reduced sulfur compounds. TRS compounds emitted are principally dimethyl sulfide and dimethyl disulfide.[5]

Uncontrolled TRS emissions from the brown stock washer system average about 0.14 g/kg ADP (0.27 lb/T ADP) at a concentration of 30 ppm. About 0.05 g/kg ADP (5-37 ppm) are emitted from the hood vent and about 0.08 g/kg ADP (240-600 ppm) are emitted from the filtrate tank (under) vent.[11]

Brown stock washer TRS emissions are affected by the wash water source, water temperature, degree of agitation and turbulence in filtrate tank, and blow tank pulp consistency.[11] TRS emissions will increase significantly if contaminanted condensate from the digester and evaporator systems are used for washing. Higher temperatures and agitation result in increased stripping of the TRS during the washing.

5.2.6 Black Liquor Oxidation System

TRS emissions from the oxidation system are created by the stripping of the reduced sulfur compounds from the black liquor by air passing through the liquor. Uncontrolled TRS emissions (principally dimethyl sulfide and dimethyl disulfide) are in the range of 0.005 to 0.37 g/kg ADP (about 3 to 335 ppm) and average 0.05 g/kg ADP (35 ppm).[12] Oxidation systems that use only molecular oxygen have the advantage of emitting virtually no off-gases because the total gas stream reacts in the sparge system.

Primary factors affecting TRS emissions from black liquor oxidation systems are the inlet sulfide content, the temperature of the black liquor, residence time, and the air flow rate per unit volume. TRS emissions tend to increase for higher liquor temperatures and greater air flow rates because of greater volatility of the gases and stripping action of the air, respectively. TRS emissions also tend to increase with increasing sulfide concentrations in the incoming black liquor and with increasing residence time.

5.2.7 Smelt Dissolving Tank

Because of the presence of a small percentage of reduced sulfur compounds in the smelt, some of these odorous materials escape the tank with the flashed steam. Uncontrolled TRS emissions are as high as 2.0 g/kg ADP (811 ppm) and as low as non-detectable. The average is about 0.1 g/kg ADP (60 ppm).[13]

Several factors affect the TRS emissions. Among these are the water used in the smelt tank, turbulence of the dissolving water, scrubbing liquor used in the particulate control device, pH of scrubbing liquor, and sulfide content of the particulate collected in the control device.[11] The use of contaminated condensate in the smelt tank or the scrubber can result in the stripping of TRS compounds into the gas stream. Turbulence can increase the stripping action. Increased H_2S formation can occur with a increase in sulfide content of the scrubbing liquid and a decrease in pH of the scrubbing liquor.

5.2.8 Condensate Stripping System

Presently there are only five condensate strippers in operation in the U.S. kraft pulp industry. Actual TRS emission data are unavailable, but TRS emissions from condensate strippers are expected to be high because the condensate contains high concentrations of dissolved TRS compounds.[14] The stripping efficiency is greater than 95 percent.[14] Uncontrolled TRS emissions are estimated to be about 1 g/kg ADP (5000 ppm) from a condensate stripping system.[15]

5.3 TYPICAL TRS EMISSIONS

Typical controlled TRS emissions are listed in Table 5.2 for each of the sources under consideration. These values represent average TRS emissions from existing facilities, based on the information listed in Appendix A. Appendix A lists emission rates for five sources (recovery furnaces, lime kilns, digesters, multiple-effect evaporators, and brown stock washers) at each kraft pulp mill in the United States. Information in Appendix A was obtained from the literature, state pollution control agencies, and the kraft pulp mills. Emission rates for uncontrolled sources are average uncontrolled values (See section 5.2) for the industry, except where actual levels are known. Controlled

Table 5-2. TRS EMISSIONS FROM THE EXISTING KRAFT PULP INDUSTRY

Source	Average Uncontrolled Level		Percent Capacity	Typical Controlled Level		Average National Emissions		
	ppm	g/kg ADP (lb/T ADP)	Controlled(1)	ppm	g/kg ADP (lb/T ADP)	ppm	g/kg ADP (lb/T ADP)	megagrams
Recovery Furnace	550	7.5 (15.0)	88.7	5-70	0.075-1.05 (0.15-2.1)	92	1.25 (2.5)	39,000
Digester System	9500	0.75 (1.5)	58.4	5	0.01 (0.02)	4050	0.32 (0.64)	10,000
Multiple-Effect Evaporator System	6800	0.5 (1.0)	58.6	5	0.01 (0.02)	2920	0.22 (0.43)	6,700
Lime Kiln	170	0.4 (0.8)	28.2	5-40	0.0125-0.1 (0.025-0.2)	130	0.31 (0.62)	9,700
Brown Stock Washer System	30	0.15 (0.3)	2.8	5	0.01 (0.02)	30	0.15 (0.3)	4,420
Black Liquor Oxidation System	35	0.05 (0.1)	2.1	0-10	0.0-0.01 (0.0-0.02)	35	0.05 (0.1)	1,470
Smelt Dissolving Tank	60	0.1 (0.2)	-	-	-	60	0.1 (0.2)	2,940
Condensate Stripper System	5000	1.0 (2.0)	100	5	0.01 (0.02)	500	0.11 (0.22)	0.4

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(1) Percentage based on mills controlled by existing state regulations, plus information collected during previous surveys.

levels listed are the actual levels where these were known; otherwise the applicable state standard is listed.

Table 5.2 also gives an estimate of the percentage of facilities presently controlled, and the TRS level to which they are most frequently controlled. These estimates on the percent of facilities controlled are based on existing or soon to be adopted state regulations. The estimates also include information obtained from various surveys of the industry on controlled facilities which are not presently covered by state regulations.

In most cases the typical emissions from existing facilities are equal to or near the uncontrolled levels. A few mills presently control TRS emissions from the brown stock washers, smelt dissolving tanks, lime kilns, and black liquor oxidation system. The other TRS sources have been controlled to some extent by a large percentage of the industry. The typical TRS emissions from these sources are discussed in the following sections.

5.3.1 Recovery Furnace System

TRS emissions from direct contact systems depend on the design and operation of the recovery furnace and, if utilized, an oxidation system. A survey of 32 recovery furnace systems where black liquor oxidation is not used shows TRS emissions ranging from 35 to 1300 ppm, representing 0.75 to 31 g/kg ADP (1.5 to 62 lb/T ADP). The average is 7.7 g/kg ADP (15.4 lb/T ADP). A survey of 17 units that utilize black liquor oxidation indicates a broad TRS emission range of 0.1 to 13.0 g/kg ADP (0.2 to 25.9 lb/T ADP), with an average value of 3.7 g/kg ADP (170 ppm).[16] TRS emissions from non-contact systems are usually confined to a narrow range of about 0.015 to 0.15 g/kg ADP (1 to 11 ppm).

Based on Appendix A, it is estimated that TRS emissions from about 89 percent of the existing furnaces are either controlled by black liquor oxidation or have been replaced with or converted to a non-contact system.

It is also estimated that the average national emission level is 1.25 g/kg ADP (92 ppmv).

5.3.2 Digester and Multiple-Effect Evaporator Systems

The digester and multiple-effect evaporators will be considered together because their emissions are normally combined for treatment. Until recently, the noncondensable gases were in most cases vented to the atmosphere uncontrolled. However, several mills now incinerate the gases to control odors. Most commonly, the gases are burned in the lime kiln. Based on EPA tests,[17] incineration can reduce TRS emissions to less than 5 ppm (0.0075 g/kg ADP). It is estimated that approximately 58 percent of the mills are incinerating these gases or are installing systems to incinerate these noncondensables. White liquor (caustic) scrubbers are used at a few mills. These scrubbers are only effective in removing hydrogen sulfide and methyl mercaptan. TRS emissions from these scrubbers are estimated to be about 0.5 g/kg ADP (1 lb/T ADP).

Based on Appendix A, the average national emission rate from digester systems is calculated to be 0.32 g/kg ADP (0.64 lb/T ADP). The average national emission rate from multiple-effect evaporators is calculated to be 0.22 g/kg ADP (0.43 lb/T ADP). These values are based upon 58 percent being controlled to 5 ppm and 42 percent being uncontrolled.

5.3.3 Lime Kiln

TRS emissions from a lime kiln installation are dependent on the operation of the kiln, the mud washing efficiency, and the type of water used in the scrubber. Only about 28 percent (See Appendix A) of the kilns are actually operated to control TRS emissions. This percentage is mostly based on kilns affected by existing state or local regulations. Based on this percentage of controlled kilns, the calculated average national emission rate for lime kilns is 0.31 g/kg ADP (130 ppm).

5.3.4 Condensate Stripping System

All the condensate strippers in operation are controlled for TRS emissions. Incineration is the control technique used at four mills. The TRS emissions from these sources are estimated to be 5 ppm as mentioned in section 5.3.2. A caustic scrubber is utilized at the remaining one mill, but no data is available on the TRS emissions.

The average national emission rate is estimated to be 0.11 g/kg ADP (0.22 lb/T ADP). This is based on 5 ppm TRS being achieved at 4 mills and 50 percent control at the mill that uses a caustic scrubber.

5.3.5 Brown Stock Washer Systems, Black Liquor Oxidation Systems, and Smelt Dissolving Tanks

These three sources are generally not controlled for TRS emissions. However, two U.S. mills incinerate the vent gases from the brown stock washer systems. Two other U.S.mills use molecular oxygen in their black liquor oxidation system, which results in no vent gases and no TRS emissions. One mill is controlling TRS emissions from the brown stock washers by a chlorine scrubber. One other mill is controlling TRS emissions from their brown stock washers and black liquor oxidation system by a chlorine gas injection system.

REFERENCES FOR CHAPTER 5

1. Shih, T. T., Hrutfiord, B. F., Sarkanen, K. V., and Johanson, L. N., Hydrogen Sulfide Vapor-Liquid Equilibrium in Aqueous Systems As a Function of Temperature and pH, TAPPI, 50(12), 630-4, 1967.
2. McKean, W. R., Hrutfiord, B. F., Sarkanen, K. V., Kinetic Analysis of Odor Formation in the Kraft Pulping Process, TAPPI, 48(12), 699-703, 1965.
3. Shih, T. T., Hrutfiord, B. F., Sarkanen, K. V., Johonson, L. N., Methyl Mercaptan Vapor-Liquid Equilibrium in Aqueous Systems As a Function of Temperature and pH, TAPPI, 50(12), 634-8, 1967.
4. Control of Atmospheric Emissions in the Wood Pulping Industry, Environmental Engineering Inc., and J. E. Sirrine Company, Final Report, EPA Contract No. CPA-22-69-18, March 15, 1970.
5. Atmospheric Emissions from the Pulp and Paper Manufacturing Industry, EPA-450/1-73-002, September 1973. (Also published by NCASI as Technical Bulletin No. 69, February 1974).
6. Reference 5, Table 14.
7. Reference 5, Table 3.
8. Reference 5, Table 7.
9. Suggested Procedures for the Conduct of Lime Kiln Studies to Define Emissions of Reduced Sulfur Through Control of Kiln and Scrubber Operating Variables, NCASI Special Report No. 70-71, January 1971.
10. Reference 5. Table A-5.
11. Factors Affecting Emission of Odorous Reduced Sulfur Compounds from Miscellaneous Kraft Process Sources, NCASI Technical Bulletin No. 60, March 1972.
12. Reference 5, Table 21.
13. Reference 5.

14. Butryn, G. L. and Ayers, K. C., Mead Experience in Steam Stripping Kraft Mill Condensate, presented at TAPPI Environmental Conference, May 14-16, 1975.

15. Air Emission Control Program For Hoerner Waldorf Corporation Mill Expansion Missoula, Montana, submitted by Hoerner Waldorf Corporation to Montana State, March 12, 1974.

16. Reference 5, Table 15.

17. Malodorous Reduced Sulfur Emissions From Incineration of Non-condensable Off-gases, EPA Test Report 73-KPM-1A.

6. CONTROL TECHNIQUES FOR TRS FROM KRAFT PULP MILLS

6.1 ALTERNATIVE CONTROL TECHNIQUES

The various control techniques that have been or can be applied to the emission sources affected by NSPS are discussed in this section. The affected sources are the recovery furnace, digester system, multiple-effect evaporator system, lime kiln, brown stock washer system, black liquor oxidation system, smelt dissolving tank, and condensate stripper system. The applicability and effectiveness of the control techniques when retrofitted on existing facilities is also discussed. Table 6-1 summarizes the control techniques and corresponding TRS levels achievable for each source of TRS. Section 6.2 discusses alternative control systems for entire kraft pulp mills. Retrofit models are presented which permit estimates to be made of required costs for retrofitting existing facilities with the alternative control systems.

6.1.1 Recovery Furnace System

TRS emissions from a recovery furnace system can originate in the recovery furnace itself, or in the direct contact evaporator if this type of evaporator is used. Most existing recovery furnace systems have direct contact evaporators. About 75 percent of the new recovery furnaces that have been installed in the last 5 years are, however, of the non-contact design. In these furnaces, the furnace flue gases never directly contact the black liquor and TRS cannot be formed in the

Table 6-1. TECHNIQUES FOR CONTROLLING TRS EMISSIONS FROM SOURCES IN A KRAFT PULP MILL

Source		Control Technique	Achievable TRS Level
Recovery furnace	1)	Process controls + black liquor oxidation	20 ppm (Old design[1] furnaces) 5 ppm (New design[2] furnaces) 25 ppm (Cross recovery furnaces)
	2)	Process controls + conversion to non-contact evaporator	20 ppm (Old design furnaces) 5 ppm (New design furnaces) 25 ppm (Cross recovery furnaces)
Digester system	1)	Caustic scrubbing	7,000 ppm[3]
	2)	Incineration	5 ppm
Multiple-effect evaporator system	1)	Caustic scrubbing	350 ppm[3]
	2)	Incineration	5 ppm
Lime kiln	1)	Process controls	40 ppm
	2)	Process controls + good mud washing	20 ppm
	3)	Process controls, good mud washing + caustic scrubbing	8 ppm
Brown stock washer system	1)	Incineration	5 ppm
Black liquor oxidation system	1)	Molecular oxygen	0 ppm
	2)	Incineration	5 ppm
Smelt dissolving tank	1)	Fresh water usage	0.0084 g/kg BLS
Condensate stripping system	1)	Caustic scrubbing	-
	2)	Incineration	5 ppm

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[1] *Old* design furnaces are defined as furnaces without welded wall or membrane wall construction or emission-control designed air systems.

[2] *New* design furnaces are defined as furnaces with *both* welded wall or membrane wall construction and emission-control designed air systems.

[3] Calculated based upon scrubber removing only hydrogen sulfide and methyl mercaptan and using reference 5 to determine percent of hydrogen sulfide and methyl mercaptan present in vent stream.

evaporator. The non-contact furnace was first introduced in 1967.

Several operating and design variables that have some effect on, or relationship to, the generation of TRS emissions in a recovery furnace have been identified. These include the quantity and manner of introduction of combustion air, the rate of solids (concentrated black liquor) feed, the degree of turbulence in the oxidation zone, the oxygen content of the flue gas, the spray pattern and droplet size of the liquor fed the furnace, and the degree of disturbance of the smelt bed.[1,2] The effect of these variables is independent of the absence or presence of a direct contact evaporator. There is no evidence that sulfide content of the liquor combusted in the furnace bears any relationship to the TRS emissions from the recovery furnace.[3] This is not to be confused, however, with sulfur compounds generated or stripped in a direct contact evaporator.

The age of existing furnaces has been reported to be a significant indicator of the furnace's ability to control TRS emissions.[4] (The typical life of a recovery furnace is considered to be 25 years.[5]) Generally,the age reflects an absence or lack of refinement in controls and instrumentation that assist the operator in maintaining close control of the process. Also, older furnaces may not incorporate recent manufacturers' improvements, such as new means of introducing air, flexibility in distributing air in the furnace and means to change air velocity at injection ports.[6] Furthermore, a major design change was made to recovery furnaces in late 1964. This change consisted of installing a membrane between the wall tubes located in front of the furnace's wall insulation. This design change made the furnace airtight. The wall insulation on furnaces without this membrane wall concept tends to deteriorate. This allows air to leak into the furnace. This in turn affects the combustion in the furnace and reduces significantly the capability of the operator to control TRS emissions.[7] These older recovery furnaces could be modified to incorporate these new design features but the modifications would be extremely expensive.[8] However, changes in operating procedures can more easily be made.

There are two control techniques to reduce TRS emissions from the direct contact evaporator: black liquor oxidation and conversion to a non-contact evaporator. Black liquor oxidation inhibits the reactions between the combustion gases and black liquor that normally generate hydrogen sulfide. This is accomplished by oxidizing the Na_2S to $Na_2S_2O_3$ in the black liquor before it enters the direct contact evaporator. In converting to a non-contact evaporator, the direct contact between furnace gases and black liquor is eliminated, and hydrogen sulfide formation is prevented.

There are several modes of operation of black liquor oxidation systems. The black liquor is sometimes oxidized before being concentrated in the multiple-effect evaporators (weak black liquor oxidation), sometimes following evaporation (strong black liquor oxidation) and sometimes both, before and after. Air is the normal oxidizing agent, but molecular oxygen is also used when available on site. Air sparging reactors are the most common units, but packed towers and bubble tray towers are also used.

In modifying an existing recovery furnace with a direct contact evaporator to a non-contact design, a black liquor evaporator (concentrator) and a second feed water economizer is necessary. In addition, elimination of the existing direct contact evaporator will result in an increased particulate concentration discharge from the furnace system into the particulate control device. To maintain particulate emissions at the original level, it may be necessary to replace the existing collector with a new higher efficiency precipitator or install an additional secondary collector. This conversion to a non-contact design has been accomplished by at least two pulp mills.

At one recovery furnace system, erected in 1966, where the conversion was made, TRS emissions decreased from approximately 400 ppm to about 10 ppm.[9] Modifications also included changes to the operation of the furnace, such as oxygen content and air distribution. Therefore, a portion of the TRS reduction is attributable to decreased emissions of TRS from the furnace system.

TRS emissions from direct contact systems depend on the design and operation of the recovery furnace and the black liquor oxidation system. An analysis of 200 stack gas samples showed the relation between oxidation efficiency and TRS emissions, presented in Table 6-2. Since these samples were taken at stacks on new recovery furnaces, the furnace TRS contribution is assumed to be negligible.[10] The data show a clear relationship between oxidation efficiency and TRS

Table 6-2

Relationship of Oxidation Efficiency and H_2S Emissions[11]

Oxidation Efficiency, Percent	Number of Samples	H_2S Emissions					
		g H_2S/Kg Pulp			Lb H_2S/Ton Pulp		
		Max	Min	Mean	Max	Min	Mean
80-85	8	4.1	0.75	2.3	8.1	1.5	4.6
85-90	15	3.0	0.05	1.6	6.0	0.1	3.2
90-94	29	3.3	0.25	1.2	6.6	0.5	2.4
94-96	18	2.2	0.05	0.9	4.3	0.1	1.8
96-98	15	1.4	0.05	0.65	2.8	0.1	1.3
98-99	19	1.1	0.0	0.35	2.1	0.0	0.7
99-100	96	1.6	0.0	0.2	3.2	0.0	0.4

emissions. Emissions from the direct contact evaporator will be eliminated by conversion to a non-contact type system.

TRS emission tests conducted during the NSPS development program indicate that TRS emissions from new recovery furnaces can be controlled to at least 5 ppm.[12] During the NSPS program, three recovery furnaces (two direct contact systems and one non-contact system) were tested by EPA. TRS emissions averaged from the individual furnaces are 1.4 ppm (6 tests, each 4-hours) 0.6 ppm (6 tests, each 4-hours), and 3.9 ppm (5 tests, each 4-hours). Only one 4-hour test showed emissions greater (about 7 ppm) than 5 ppm.

One furnace manufacturer indicates that many recovery furnaces built since 1965 are basically the same design as new furnaces built today, and that these should also be capable of achieving 5 ppm TRS with good process control and either black liquor oxidation or conversion to a non-contact evaporator.[13] These existing recovery furnaces, defined as "new design" furnaces, were designed for low TRS emissions (i.e., incorporates manufacturer's improvements) and will have stated in their contracts that these furnaces were constructed with air pollution control as an objective.[14] Recovery furnaces, mainly those built before 1965, that were not constructed with air pollution control as an objective, have a somewhat different design, as mentioned previously, and are not capable of achieving 5 ppm TRS (4-hour average basis). These furnaces, defined as "old design" furnaces, can generally achieve about 15 to 20 ppm TRS with good process control and black liquor oxidation or conversion to a non-contact evaporator.[15] This TRS level (15 to 20 ppm) is presently being achieved by existing recovery furnaces (see AppendixB), many built before 1965, in those states which have TRS regulations of 17.5 ppm (daily average).[16] Some existing furnaces may have difficulty achieving even this level (20 ppm) if they are operating at a much higher firing rate than originally designed or do not have sufficient combustion control capability.

Cross recovery liquors are somewhat different than straight kraft liquor, and, therefore, it is possible that the TRS emissions from a cross recovery furnace are not controllable to the same degree as are those from the straight kraft furnace. There are three reasons why TRS emissions may be higher from cross recovery furnaces.[17] The first relates to the sulfur content of the liquor which is higher with this process than in straight kraft processes. In cross recovery operations, the heat content of the black liquor is lower than found in straight kraft mills. This is because the NSSC process gives higher pulp yields than the kraft process and, as a consequence, the spent liquor associated with the NSSC process contains less organic content. Therefore, its Btu value is lower as compared with kraft black liquor. The third reason pertains to the restriction on excess oxygen available in cross recovery furnaces to oxidize the relatively large quantities of volatile sulfur compounds given off as a consequence of the heavy sulfur loading and lower furnace operating temperatures. If enough excess oxygen is supplied to completely oxidize all volatile sulfur compounds, a sticky dust problem will develop which can plug up the precipitator and render furnace operation impossible.

Based on a study[18] conducted on one cross-recovery furnace, cross-recovery furnaces which experience green liquor sulfidities in excess of 28 percent and liquor mixtures of more than 7 percent NSSC on an air dry ton basis can not achieve the same TRS levels as straight kraft recovery furnaces. Emission data reported in the study indicate that TRS emission levels of 25 ppm, corrected to 8 percent oxygen, can be achieved from well-controlled cross-recovery furnaces.

A recently developed control technique for recovery furnaces is alkaline adsorption with carbon activated oxidation of the scrubbing solution. Pilot plant studies indicate that this technique can reduce TRS emissions from 20 to 2500 ppm to between 1 and 10 ppm.[19] Reduction in particulate and SO_2 emissions are also reportedly achieved. This technique could be used to control TRS emissions on those older existing furnaces or cross recovery furnaces which do not have the combustion control capability for low TRS emissions. This technique could prevent the need to replace or reduce the load on older existing furnaces that are not capable of achieving the necessary TRS regulations.

6.1.2 Digester and Multiple-Effect Evaporator Systems

The digesters and multiple-effect evaporators will be considered together because non-condensable gases discharged from these two sources are normally combined for treatment. At least half the mills are incinerating the gases to destroy odors. Most commonly, the gases are burned in the lime kiln. However, a few special gas-fired incinerators are also used, either as backup for the kiln when it is shutdown, or as the full-time control device.

Retrofitting an existing mill to handle and incinerate these non-condensable gases is apparently no significant problem. Generally, it is simply a matter of ducting the gases to the kiln or incinerator and installing necessary condensers and gas holding equipment. The non-condensable gases are added to the primary air to the kiln. This retrofit situation has now been performed at over sixty mills.

The blow gases from batch digesters are generated in strong bursts that normally exceed the capacity of the lime kiln. For this reason, special gas handling equipment has been developed to make the gas flows more uniform.[20] Adjustable volume gasholders, with movable diaphragms or floating tops, receive the gas surges, and a small steady stream is bled to the kiln. Although the non-condensable gases form explosive mixtures in air, possible explosion hazards have been minimized by the development of appropriate gasholding systems, flame arrestors and rupture disks in the gasholding ducts, and flame-out controls at the lime kiln. Incineration of these gases in existing process equipment such as the lime kiln is particularly attractive since no additional fuel is required to achieve effective emission control.

Scrubbers are used at a few existing mills. White liquor, the usual scrubbing medium, is effective for removing hydrogen sulfide and methyl mercaptan, but not dimethyl sulfide or dimethyl disulfide.[21] At least 3 mills scrub the noncondensable gases before incineration to: (1) recover sulfur, (2) condense steam, and (3) remove turpentine vapors and mist, thereby reducing the explosion hazards.

Combustion of noncondensable gases in a lime kiln or gas-fired incinerator provides nearly complete destruction of TRS compounds. During an EPA test (conducted for NSPS) on a separate incinerator burning noncondensables from a digester system and a multiple effect evaporator system, the residual unburned TRS was less than 5 ppm (0.01 g/kg ADP)[22]. The TRS test results (4-hour averages) of the four tests conducted ranged between 0.5 and 3.0 ppm, and averaged 1.5 ppm (dry gas basis). During the tests, the incinerator was operating at 1000°F (measured) with a calculated retention time for the gases of at least 0.5 seconds.

Scrubber efficiencies are much lower than properly operated incinerators because only hydrogen sulfide and methyl mercaptan react with the alkaline medium. The composition of noncondensable gases is highly variable, but on the average hydrogen sulfide and methyl mercaptan comprise about half the TRS compounds.[23] Uncontrolled emissions are 9,500 ppm from the digester system and 6700 ppm from the multiple-effect evaporator system.[24] Since caustic scrubbing is only effective in controlling hydrogen sulfide and methyl mercaptan, alkaline scrubber efficiencies are roughly only 50 percent. TRS emissions from a scrubber are calculated to be about 0.63 g/kg ADP (0.59 g/kg ADP from digester system and 0.04 g/kg ADP from multiple-effect evaporator system) or about 7500 ppm.

6.1.3 Lime Kiln

TRS emissions, principally hydrogen sulfide, can originate from two areas in the lime kiln installation, the lime kiln proper and a scrubber that serves as the particulate control device. TRS emissions from the lime kiln installation are controlled by maintaining proper process conditions. The most important parameters that were identified in an industry (National Council of the Pulp and Paper Industry for Air and Stream Improvement) study[25] include the temperature at the cold end (point of exhaust discharge) of the kiln, the oxygen content of the gases leaving the kiln, the sulfide content of the lime mud fed to the kiln, and the pH and sulfide content of the water used in a particulate scrubber. If contaminated condensate is used as the scrubbing medium, the exhaust gases could strip out the dissolved TRS and increase the TRS emissions from the lime kiln installation. Scrubbing the exhaust gases with a caustic solution can reduce the TRS emissions from a lime kiln.[26]

The amount of retrofitting necessary to achieve proper process conditions depends on the design of the existing kiln installation. If the existing kiln does not achieve sufficient oxygen levels, increased fan capacity or changes to the scrubber system may be necessary to increase the air flow through the kiln. Molecular oxygen can also be used to replace a portion of the combustion air to increase oxygen levels. Additional lime mud washing capacity may also be necessary to reduce the sulfide content of the mud and thereby reduce TRS emissions. This may require replacement of existing centrifuges with more efficient vacuum drum filters, and the addition of another mud washing stage. Furthermore, a mill presently using condensate that contains dissolved reduced sulfur compounds for a scrubbing medium would have to either install a condensate stripper to remove the dissolved TRS prior to the scrubber or replace the condensate with fresh water.

TRS emissions from existing lime kilns range from about 0.01 to 2.0 g/kg ADP (4 to 840 ppm), depending on the degree of control, with an average of about 0.4 g/kg ADP (168 ppm).[27] EPA tests (conducted for NSPS development) on two lime kilns indicate that lime kiln TRS emissions can be reduced to below 20 ppm (12-hour average) using process controls. Another lime kiln using caustic scrubbing in addition to process control is capable, based on EPA results, of TRS emissions below 8 ppm (12-hour average). When tested by EPA, all three lime kilns were burning non-condensable gases from the digester system and multiple-effect evaporator system.

It appears that existing lime kilns can be retrofitted to also achieve low TRS emissions. TRS emissions from two existing lime kiln installations have reportedly been reduced from over 100 ppm to less than 20 ppm by modifying the lime mud washing systems and making adjustments in the process operation.[28] However, the TRS levels to which existing kilns can be retrofitted depends on the load at which the kiln is normally operated. If the kiln is operated sufficiently over design capacity, it may be very difficult to obtain the oxygen levels necessary for low TRS emissions (about 20 ppm). Discussions with the kraft industry indicate that TRS emissions from these lime kilns can be reduced, however, to about 40 ppm.

6.1.4 Brown Stock Washer System

Nearly all existing kraft mills vent the brown stock washing system gases directly to the atmosphere without control. However, at least three mills in the United States and Canada, and one in Sweden, utilize the gases as combustion air in a recovery furnace. The furnace systems handling these gases are newer furnace systems which were designed to burn the washer gases. No existing recovery furnace (not designed for burning these gases) has yet been used to incinerate the washer gases.

As discussed in section 6.1.2 the residual TRS after incineration is very low, less than 5 ppm (0.01 g/kg ADP). Since the gas volume from the washer drums is large, about 112 m^3/Mg (150 CFM/TPD),[29] the most likely equipment for combustion is a recovery furnace or power boiler. The gases, due to their large volume, would have to supplement the recovery furnace's combustion air requirements. Even if the washers were enclosed with tight hoods, the gas volume would be too large to burn in a lime kiln. The actual gas volume handled at one mill is 75 m^3/Mg (100 CFM/TPD). The gas volume that would need to be handled at other existing mills can be higher or lower depending upon tightness of hooding and degree of condensing.

The vent gases from the filtrate tank are considerably smaller in volume, about 4.5 m^3/Mg (6 CFM/TPD).[30] This stream is sufficiently small for combustion in a lime kiln, or blended with the hood vent gas and burned in a recovery furnace.

Incineration of the washer gases in a recovery furnace will not affect furnace operation provided the moisture content of the gases is not too great.[31] High moisture content can increase gaseous sulfur emissions and produce unsafe operating conditions. Red (furnace) temperature decreases almost linearly with increased content of vaporized water in the combustion air because of sensible heat losses. With decreased bed temperatures, SO_2 emissions increase at a rapid rate and reduced sulfur compounds become increasingly difficult to control.[32] Water entrained in the combustion gases can create extremely dangerous conditions such as smelt-water explosions.

One furnace manufacturer recommends that the washer gases be incinerated only in the secondary or tertiary air zones of the furnace. This would keep the moist washer gases away from the smelt bed. Burning the gases only in the secondary or tertiary zones may affect the flexibility of the recovery furnace, however, since the operator would not have the ability to vary the air flow rate to each zone.[33]

High moisture content would result in an increase in gas flow and reduce the capacity of the recovery furnace.

An alternative to incineration of brown stock washer gases is chemical scrubbing. White liquor (caustic) scrubbing, as previously mentioned, is only effective in controlling hydrogen sulfide and methyl mercaptan. However, the TRS emissions from a brown stock washer system are principally dimethyl sulfide and dimethyl disulfide.[34] A more effective system is reportedly a chlorination-caustic scrubbing system. In this system, the chlorine [illegible]sorbs and oxidizes the dimethyl sulfide and dimethyl disulfide.[35] This technique was installed at one mill in February 1976 and tests conducted at that time demonstrated TRS emissions of less than 5 ppm.[36] Another technique is chlorine gas injection. This technique is used at one mill and tests conducted demonstrated TRS emissions of less than 5 ppm and a control efficiency of 80 percent.[37]

6.1.5 Black Liquor Oxidation System.

The vent gases from nearly all existing black liquor oxidation (BLO) systems are emitted directly to the atmosphere without control.

One control technique is incineration. Incineration has proved highly effective in controlling similar streams in some mills, for example, the vent gases from pulp washing systems, the noncondensable gases from digesters and multiple-effect evaporators, and vent gases from condensate strippers. Similar to the pulp washing system, incineration in the recovery furnace or power boiler is most likely, since the BLO gas volume is usually too large to be handled by an existing kiln. This would result in no significant fuel penalty.

Because of the high moisture content of the BLO gases, it would be necessary to use condensers to reduce the moisture content before burning, especially if the moist washer gases are burned in the same furnace. Incineration of these moist gases in the furnace would probably cause increased corrosion problems in the forced-draft fan ductwork and the forced-draft fan itself. This would probably necessitate the replacement of this equipment with corrosion-resistant equipment. A larger forced-draft fan may be necessary to handle the increased mass flow due to the high moisture content of the gases, even after using condensers.[38]

The recovery furnace operation should not be adversely affected by burning the BLO gases, even in combination with the washer gases, provided the moisture content is sufficiently reduced and the gases are burned high in the furnace.[39] Since the BLO gases are deficient in oxygen, one furnace manufacturer suggests burning them in the secondary or tertiary air zone but states that the gases should still contain sufficient oxygen to preclude adversely affecting the furnace operation.

As mentioned in Section 6.1.4, the operational flexibility of the furnace is reduced because a portion (BLO gases and washer gases) of the total combustion air must always be introduced into the secondary and tertiary air zones and cannot be used in the primary air zone when air in this zone is needed to adjust furnace operation.

Emissions will be reduced to low levels if oxidation vent gases are burned. Since these gases contain the same TRS compounds present in the digester and multiple-effect evaporator off-gases which EPA tested after incineration, TRS combustion residuals of the BLO vent gas will be less than 5 ppm.

A second control technique is the use of molecular oxygen in oxidation systems instead of air. At least two mills in the United States now oxidize black liquor by pumping oxygen directly into the black liquor lines. There are no vent gases from this closed system. The economic feasibility of such a system depends largely on the price and availability of oxygen.

Another technique is chlorine gas injection. This technique is used at one mill on the vent gases from primary oxidation system. Tests conducted demonstrated TRS emissions of less than 5 ppm and a control efficiency of 95 percent.[40]

6.1.6 Smelt Dissolving Tank

Smelt dissolving tank TRS emissions are governed by process conditions; that is; the presence of reduced sulfur compounds either in the smelt or the water. The principal control option available is the choice of water in the smelt dissolving tank or the particulate control device. Clean water, low in dissolved sulfides, is preferable, although low emissions have been reported with nearly all process streams.[44] If TRS emissions are high and no particulate control device (scrubber) is used, a wet scrubber (e.g., packed tower) can be used to control the TRS emissions. This scrubber would also result in controlling particulate emissions. One mill reportedly reduced TRS emissions over 95 percent from a level of about 0.19 g/kg of black liquor solids (BLS) (0.56 lb/T ADP) when a packed scrubber tower was installed.[42]

TRS emissions from smelt dissolving tanks are normally low and average about 0.007 g/kg BLS (0.02 lb/T ADP).[43] EPA tests on two smelt dissolving tanks indicate TRS emissions below 0.0034 g/kg BLS (8 ppm). These levels can be achieved on both new and existing smelt tanks. Both these smelt tanks have wet scrubbers for controlling particulates. Weak wash liquor was used as the scrubbing medium in both scrubbers.

6.1.7 Condensate Stripping System

In at least four United States mills, dissolved sulfides and other volatile compounds are stripped from the digester and evaporator condensates prior to discharge to treatment ponds. One mill, which uses steam as the stripping medium, discharges the gases from the stripper column to a lime kiln. Two mills use air as the stripping medium. One of these incineratesthe stripper gases in a separate incinerator, while the other incinerates the gases in the recovery furnace. One mill, which uses steam, is presently scrubbing the stripper gases with white liquor, but this technique is not as effective as incineration.[44]

As mentioned in Section 6.1.2, incineration has proven to reduce TRS levels from digester and multiple-effect evaporator systems to less than 5 ppm. Since the vent gas from condensate strippers contains the same TRS compounds present in the digester and multiple-effect evaporator gases, TRS emissions in the condensate stripper gases after incineration can be reduced to 5 ppm (0.01 g/kg ADP).

6.2 SUMMARY OF RETROFIT MODELS

Section 6.1.1 through Section 6.1.7 have examined the various control techniques that can be applied to each source of TRS emissions and have quantified the emission levels that can be achieved by applying these controls. The economic and environmental impact of applying these alternative control techniques will be discussed in Chapters 8 and 9, respectively. In order to assess the impacts of applying controls simultaneously to the various TRS sources in the entire mill, various alternative control systems (retrofit models) were developed. The alternative systems chosen range from controlling each TRS source to the best achievable level, to controlling only the major TRS sources with techniques less effective than best available technology. The six retrofit models that use alternative control systems are listed in Table 6-2. These six control systems were selected because the differences between systems reflect major differences in the types and costs of retrofits that would be carried out at an existing kraft mill. The economic and environmental impacts of these retrofit models will be analyzed in conjunction with the present controls already installed at each existing kraft pulp mill. The six control systems are discussed below.

Retrofit Model No. 1: All eight TRS sources are controlled to the level of best available control technology. This system will

Table 6-2. POSSIBLE CONTROL SYSTEMS FOR EXISTING KRAFT PULP MILLS

Source	Control Systems/emission level (ppm)					
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Recovery furnace	Process control + BLO/5 ppm	Process control + BLO/5 ppm	Process control + BLO/20 ppm*	Process control + BLO/20 ppm*	Process control + BLO/20 ppm*	Process control + BLO/5 ppm
Digester system	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm
Multiple-effect evaporator system	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm
Lime kiln	Process controls + caustic scrubbing/8 ppm	Process controls + caustic scrubbing/8 ppm	Process controls + caustic scrub bing/8 ppm	Process controls/ 20 ppm	Process controls/ 40 ppm	Process controls/ 40 ppm
Brown stock washer system	Incineration/5ppm	No control	No control	No control	No control	No control
Black liquor oxidation system	Incineration/5 ppm	No control	No control	No control	No control	No control
Smelt dissolving tank	Fresh water/8 ppm (.0084 g/kg BLS)	Fresh water/8 ppm	Fresh water/8 ppm	Fresh water/8 ppm	Fresh water/8 ppm	Fresh water/8 ppm
Condensate stripper system	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm	Incineration/5 ppm

*The 20 ppm levels applies to old design furnaces; new design furnaces can achieve 5 ppm with application of the same control technology (two-stage BLO).

result in the lowest TRS emissions from a kraft pulp mill and will require installation of a new furnace if the existing furnace is relatively old and cannot achieve 5 ppm TRS. In most cases, this system will also require caustic addition to the existing scrubber and the improvement or replacement of the lime mud washing facility in order to achieve a TRS level of 8 ppm from the lime kiln. TRS emissions from the smelt dissolving tank will be controlled by using fresh water in the tank and the particulate control device. Incineration will be used to control TRS emissions from the digester system, multiple-effect evaporator system, brown stock washer system, black liquor oxidation system and condensate stripping system. The gases from the digesters, multiple-effect evaporators and condensate strippers will be incinerated in the lime kilns. The gases from the washers and oxidation system for purposes of impact analysis are assumed to be burned in a separate incinerator since no existing recovery furnace has been modified to handle these gases.

Retrofit Model No. 2: This control system is similar to Retrofit Model No. 1 except that the vent gases from the washer system and the BLO system are not incinerated. This system was chosen as a model because, based on the economic analysis performed for NSPS development, these two smaller TRS emission sources are less cost effective to control than the other sources. It is assumed that these two sources would be combined for treatment. The cost of controlling one source is related to the cost of controlling the other source because one incinerator would be installed to handle both gas streams. Therefore, modifications made to an existing mill would generally be the same whether both or only one of these sources is controlled.

Retrofit Model No. 3: This control system is similar to Retrofit Model No. 2 except that less effective control of the recovery furnace is allowed, resulting in a higher TRS level from this unit. This system was chosen because the higher TRS level (20 ppm) will allow mainly older recovery furnaces (mostly those built before 1965) to remain in operation. The 5 ppm level as required in Retrofit Models No. 1 and No. 2 would probably require these older furnaces to be replaced. The cost impact of Models No. 1 and 2, if furnace replacement is necessary, will be substantially greater than that of Model No. 3.

Retrofit Model No. 4: This control system is similar to retrofit Model No. 3 except that the lime kiln TRS level has been relaxed from 8 to 20 ppm. This system would permit many kilns to achieve this level without using caustic scrubbing. The TRS emissions from the lime kiln would be controlled by process controls and require the lime mud washing facility to be improved or replaced. Caustic scrubbing would be a major expense if the caustic cannot be used in the pulping process or a wet scrubber is not already used for particulate control.

Retrofit Model No. 5: This control system is similar to Retrofit Model No. 4 except that the lime kiln TRS level has been relaxed from 20 to 40 ppm. This system would permit many kilns to achieve the level without modifying the lime mud washing installation. TRS emissions from the lime kilns would be controlled by using process controls on the kiln itself. Modifications to the mud washing system are a major expense (see Chapter 8) in controlling TRS emissions from an existing kraft pulp mill.

Retrofit Model No. 6: This system is similar to Retrofit Model No. 5 except that all recovery furnaces are controlled to 5 ppm TRS rather than 20 ppm. This system was chosen to determine the differences on the impacts in relaxing controls on the lime kiln (Model No. 5) in comparison to relaxing controls on the recovery furnace (Model No. 3).

6.3 INSTALLATION AND START-UP TIME

The amount of time necessary to retrofit an existing kraft mill depends on what TRS sources are to be controlled and what technologies are to be used. It should also be pointed out that actual time requirements to implement a given control technology can vary widely depending upon such factors as space limitations, weather conditions, lack of available utilities, delays in equipment delivery, and time required to develop engineering data.

Table 6-3 presents estimates of the normal length of time required to retrofit the various sources in order to bring them into compliance. Table 6-3 shows that the time necessary for initial design and approval can vary from 6 months to 3 years, depending on the source and the complexity of retrofitting that source. This time period includes:

a. Engineering design of the overall project;

b. Project fund approval;

c. Control agency approval;

d. Order placement.

Table 6-3 also presents estimates of the amount of time required for installation of the necessary equipment. This time is for the

Table 6-3. DESIGN AND INSTALLATION TIMES*

TRS source	Design and approval** (months)	Installation*** (months)
Recovery furnace	18-36	12-36
Digester system	6	18
Multiple-effect evaporator system	6	18
Lime kiln	6-24	24
Brown stock washer system	6-24	12-15
Black liquor oxidation system	6	12
Smelt dissolving tank	6	18
Condensate stripping system	6	18

*Based on discussions with various companies and manufacturers. The actual times of approval and installation may over-lap to some extent.

**This time period includes: engineering design of the overall project; project fund approval; control agency approval; and order placement.

***From the order date to start-up (start-up excluded).

period from the order date to start-up (start-up excluded). This installation time varies from about one year for installing black liquor oxidation system to three years for installing a new recovery furnace.

REFERENCES FOR CHAPTER 6

1. Factors Affecting Reduced Sulfur Emissions from the Kraft Recovery Furnace and Direct Contact Evaporator, NCASI Technical Bulletin No. 44, December 1969.

2. The Effect of Combustion Variables on the Release of Odorous Sulfur Compounds from a Kraft Recovery Furnace, Thoen, G. N., De Haas, G. G., Tallent, R. G., and Davis, A. S., TAPPI, 51(8):329-333, August 1968.

3. Op. cit., Reference 1, page 28.

4. Op. cit., Reference 1, page 31.

5. Meeting Report - Babcock & Wilcox Company and EPA, Durham, NC, May 1, 1975.

6. Op. cit., Reference 4.

7. Op. cit., Reference 5.

8. Op. cit., Reference 5.

9. Improved Air Pollution Control for a Kraft Recovery Boiler: Modified Recovery Boiler No. 3, Henning, K., Anderson, W., and Ryan, J., EPA Report No. 650/2-74-071-a, August 1974.

10. Survey of Current Black Liquor Oxidation Practices in the Kraft Industry, NCASI Technical Bulletin No. 39, December 1968.

11. Op. cit., Reference 10, Table 6.

12. Standards Support and Environmental Impact Document, Volume 1: Proposed Standards of Performance for Kraft Pulp Mills, Environmental Protection Agency, September 1976.

13. Letter from J. W. Kisner of Babcock & Wilcox Company to James Eddinger of EPA, dated May 27, 1975.

14. Presentation given by Julius Gommi of Combustion Engineering at the NAPCTAC meeting in Raleigh, North Carolina, on March 3, 1977.

15. Op. cit., Reference 13.

16. Monthly Reports obtained from the Washington Department of Ecology and the Oregon Department of Environmental Quality.

17. A Report on the Study of TRS Emissions from a NSSC-Kraft Recovery Boiler, Container Corporation of America, March 9, 1977.

18. Op. cit., Reference 17, page 2.
Ecology and the Oregon Department of Environmental Quality.

19. Considerations in the Design for TRS and Particulate Recovery from Effluents of Kraft Recovery Furnaces, Teller, A. J., and Amberg, H. R., Preprint, TAPPI Environmental Conference, May 1975.

20. Current Practices in Thermal Oxidation of Noncondensable Gases in the Kraft Industry, NCASI Technical Bulletin No. 34, November 1967.

21. Atmospheric Emissions from the Pulp and Paper Manufacturing Industry, EPA-450/1-73-002, September 1973. (Also published by NCASI as Technical Bulleton No. 69, February 1974.)

22. Malodorous Reduced Sulfur Emissions from Incineration of Noncondensable Off-Gases, EPA Test Report No. 73-KPM-1A, 1973.

23. Op. cit., Reference 21, Tables 3, 5, and 7.

24. Op. cit., Reference 21, Tables 3, 5, and 7.

25. Suggested Procedures for the Conduct of Lime Kiln Studies to Define Emissions of Reduced Sulfur Through Control of Kiln and Scrubber Operating Variables, NCASI Special Report No. 70-71, January 1971.

26. Kraft Odor Control at Mead Papers, Ayers, K. C., Clutter, L. W., and Adams, A. B., TAPPI, September 1974.

27. Op. cit., Reference 21, Table A-5.

28. Trip Report on Visit to the Champion International Mill in Pasadena, Texas, on April 4, 1975.

29. *Factors Affecting Emission of Odorous Reduced Sulfur Compounds from Miscellaneous Kraft Process Sources*, NCASI Technical Bulletin No. 60, March 1972.

30. Op. cit., Reference 29.

31. Op. cit., Reference 13.

32. Letter from S. T. Potterton of Babcock & Wilcox Company to James Eddinger of EPA, dated July 23, 1974.

33. Op. cit., Reference 5.

34. Op. cit., Reference 29, page 6.

35. Letter from H. M. Patterson of Oregon Department of Environmental Quality to James Eddinger of EPA, dated April 4, 1975; and letter from L. A. Broeren of Crown Zellerbach Corporation to Doug Ober of Oregon Department of Environmental Quality, dated January 10, 1975.

36. Telephone conversation between Chuck Clinton of Oregon Department of Environmental Quality and James Eddinger of EPA on December 6, 1976.

37. Monthly Reports obtained from the Humboldt County Air Pollution Control District.

38. Letter from Russell Blosser of NCASI to Paul Boys of EPA dated November 17, 1972.

39. Op. cit., Reference 19.

40. Op. cit., Reference 37.

41. Op. cit., Reference 3, Table 25.

42. Telephone conversation between Richard Labrecque of S. D. Warren Company and James Eddinger of EPA on July 19, 1973.

43. Op. cit., Reference 41.

44. Private communication between Arthur Plummer of Chesapeake Corporation and James Eddinger of EPA on February 13, 1975.

CHAPTER 7. EMISSION MONITORING AND COMPLIANCE TESTING TECHNIQUES AND COSTS

This chapter discusses the various monitoring and compliance testing methods that have or could be used in the kraft pulp industry, and also discusses the rationale leading to the selection of the reference test method used for the TRS source tests conducted during the SPNSS development program.

7.1 EMISSION MEASUREMENT TECHNIQUES

7.1.1 Emission Monitoring

Performance specifications for oxygen continuous monitors have already been published in 40 CFR, Part 60, Appendix B, Performance Specification Three, but it has not been demonstrated that these monitors will perform in the same manner when used at a kraft pulp mill. There is, however, no technical reason to believe that they will not be able to meet these requirements. A number of commercially available instruments are capable of meeting the performance specifications. The cost of one of these instruments, installed, is in the range of $9,000 to $11,000.

Equipment is also commercially available for temperature monitoring. This can be accomplished using a thermocouple, electronic cold junction, and a millivolt strip-chart recorder. A system such as this could be purchased for less than $2,000. Instrumentation is also available for continuously monitoring the pressure loss of the gas stream through the scrubber and for monitoring the scrubbing liquid supply pressure to the scrubber.

At present, there are several types of instruments that have been used to successfully measure TRS on a short-term basis. However, some questions remain about their reliability for data gathering on a continuous basis. The GC technique described in Method 16 was not designed to be used as a continuous monitor and its suitability for this purpose has not yet been evaluated. There are other systems which have been used on a long-term basis but necessary maintenance and quality control procedures to insure that these monitors are operating properly are still being developed. Work is presently underway in cooperation with the National Council for Air and Stream Improvement to evaluate a number of different types of systems for their suitability as continuous monitors. Ultimately, this should result in published performance specifications for TRS monitors.

7.1.2 Compliance Testing

7.1.2.1 TRS Compounds - The need for an effective test method for measurement of reduced sulfur emissions from stationary sources resulted from a new source performance standard (NSPS) program to establish performance standards for a variety of kraft mill unit processes with respect to malodorous emissions. As with previous NSPS programs, test methodology was needed to gather: (a) accurate data which would demonstrate emission limitations attainable through the use of best available emission control systems; and (b) enough sampling and analytical data such that a reference method for performance testing could be prescribed.

At the inception of the NSPS kraft mill program in January 1972, a survey was made to evaluate existing test methods for potential use. This survey included a review of the literature, contact with mill personnel, and review of previous research and evaluation of analytical techniques by the Environmental Protection Agency (EPA). Since the degree to which methods are available for field use in odor measurements is directly related to the complexity of the odorant mixture to be measured, it was fortunate that the nature of emissions from kraft pulping operations had been well-defined. Emissions consist primarily of sulfur dioxide (SO_2) and four reduced sulfur compounds - hydrogen sulfide (H_2S), methyl mercaptan (CH_3SH), dimethyl sulfide (DMS), and dimethyl disulfide (DMDS). These compounds are highly reactive, particularly the H_2S-SO_2 mixture which may form elemental sulfur, and are present in low concentrations in well-controlled sources. In addition, the sources of these emissions (recovery furnaces, lime kilns, smelt dissolving tanks, digesters, multiple-effect evaporators, washer systems, oxidation systems, and condensate strippers) are characterized by high temperatures and moist, particulate-laden effluent streams.

After careful consideration, it was determined that an additive total reduced sulfur (TRS) standard, reflecting all sulfur compounds present minus SO_2, was desired. Considering this and the previously mentioned source conditions, a field method which could measure reduced sulfur compounds, either individually or collectively, was sought.

7.1.2.1.1 Methods surveyed - A review of the literature revealed that analytical methods fell into four main categories: colorimetry, direct spectrophotometry, coulometry, and gas chromatography. Although most of the methods surveyed were developed for measurement of ambient concentrations, this did not preclude their possible application to the measurement of stack emissions.

Colorimetry - A sample is bubbled through a solution which selectively absorbs the component or components desired. The absorbed compound is then reacted with specific reagent to form a characteristic color which is measured spectrophotometrically.

An example of a colorimetric method is the methylene blue method which involves the absorption of TRS compounds in an alkaline suspension of cadmium hydroxide to form a cadmium sulfide precipitate. The precipitate is then reacted with a strongly acidic solution of N, N, dimethyl-P-phenylenediamine and ferric chloride to give methylene blue, which is measured spectrophotometrically. Automated sampling and analytical trains using sequential techniques are available for this procedure. Inherent deficiencies for stack sampling applications include variable collection efficiency, range limitations, and interferences from oxidants.

Another colorimetric method is the use of paper tape samplers impregnated with either lead acetate or cadmium hydroxide. These compounds react specifically with H_2S and the resultant colored compound can be measured directly with a densitometer. Tape samplers would not be appropriate for all TRS compounds unless they were all reduced quantitatively to H_2S. In addition, the range is limited and the method suffers from light sensitivity, fading, the necessity for precise humidity control, and variability in tape response.

Spectrophotometry - The use of infrared and mass spectrophotometry and other sophisticated spectroscopic methods for analysis of individual odorants is well established. However, these methods were considered expensive, time consuming, and not suitable for routine field applications.

One promising method in this area was split-beam ultraviolet spectrophotometry, which utilizes the strong absorption of ultraviolet radiation at 282 nm by SO_2. In this method, the gas sample is mixed with air, filtered, and split into two streams. One stream passes through a catalytic oxidation furnace where sulfur constituents are oxidized to SO_2 and then through an optical cell where its absorbance is measured. The second stream passes through a dummy furnace and then into a reference optical cell. The difference in abosrbance values between the two cells is a measure of the non-SO_2 sulfur constituents in the sample stream. The system is capable of SO_2/TRS concentrations in the range of 10 to 2500 ppm. Since well-controlled kraft mill sources fall below the minimum range of 10 ppm, this method was considered not applicable.

Coulometry - Coulometric titration is based on the principle of electrolytically generating a selected titrant in a titration cell. The titrant may be a free halogen (bromine or iodine) in aqueous solution as an oxidizing agent, or a metal ion (silver), as a reducing agent. The electrolytic current required to generate the titrant, as it is consumed, is a linear measure of the concentration of reactive compounds in the gas sample.

Gas Chromatography - This system is based on the ability of the gas chromatographic columns to separate individual sulfur compounds, which are then determined individually by various analytical techniques. The most sensitive determination is the flame photometric detector (FPD). This technique involves measurement of light emitted from the excited SO_2 species formed when a sulfur compound is burned in a hydrogen-rich flame.

7.1.2.1.2 Methods used for data gathering -

Analytical Techniques - Based on the survey, the GC/FPD technique was considered to be the most promising and was selected for field evaluation. At several of the plants, the coulometric titrator was also tried since this instrument was widely used by the industry at the time.

Sample Collection - Considering the sulfur compound reactivity, high moisture, and presence of particulate matter, EPA developed a special sample handling system. It utilizes a sampling probe enclosed in a stainless steel sheath with inlet ports perpendicular to the stack wall. A deflector shield is fixed on the underside to deflect the heavier particles while the probe is packed with glass wool to trap finer particles. Teflon tubing heated to 250°F is used to carry the sample from the probe to a dilution system where the sample is routinely diluted 1:9 with clean dry air. The heated sample line prevents condensation and teflon does not react with sulfur compounds. After the sample is diluted in a heated dilution box, its moisture content is reduced so that the dew point is below ambient temperature, preventing condensation and sample loss during analysis.

Calibration of Instruments - For delivery to and calibration of analytical instruments, a special system containing premeation tubes with appropriate concentrations of SO_2, H_2S, DMS, DMDS, and CH_3SH were installed into the sampling and analytical system. These gas permeation tube standards were developed by EPA personnel specifically for use with GC systems.

Field Evaluation - Since 1972, EPA has used the sample delivery system, dilution system, calibration system, and the GC/FPD methods at a number of kraft mills. Two separate GC/FPD systems were employed to facilitate the rapid analysis of both high and low molecular weight sulfur compounds. One system resolved H_2S, SO_2, CH_3SH, and DMS, while the other simultaneously resolved DMDS and other high molecular weight homologs. To ensure reliability of the data, the GC/FPD systems were frequently calibrated with standards of each of the sulfur compounds.

Field experience has shown that the GC/FPD method is the most reliable, sensitive, and precise for determination of TRS. This has also been substantiated via verbal communications with industry experts. There, may, however, be some loss of precision in using this method on sources having high levels of SO_2 in comparison to the level of TRS. Further developmental work is underway to eliminate this problem and the necessary changes will be made in Method 16 as soon as the work is completed.

Conversely, at six of these kraft mills, two different coulometric instruments have yielded poor results, possibly due to the low concentrations encountered and operational problems. This instrument is unacceptable for compliance testing.

7.1.2.1.1 Compliance method - As the result of field experience of testing TRS compounds at kraft mills, Method 16 was prepared for determining compliance with new source performance standards. This method requires use of a GC/FPD system using the same measuring principle as used for the data gathering process. Design specifications for the required dilution system, calibration techniques, and instrumentation that was considered necessary to insure accuracy, precision, and reliability are specified.

8. COST ANALYSIS OF ALTERNATIVE EMISSION CONTROL SYSTEMS

8.1 Introduction

The purpose of this chapter is to develop estimates of retrofit costs for alternative emission control systems for reduction of total reduced sulfur (TRS) emissions at existing kraft pulp mills. Capital and annualized costs will be developed for alternative controls on each affected facility on three sizes of kraft pulp mills: 500, 1000, and 1500 ton per day mills. Following this, aggregate costs will be presented for six alternative emission control systems on a 1000 TPD kraft pulp mill. Finally, a summary of an analysis for estimating industry-wide costs will be presented.

The determination of incremental costs for the various control alternatives over state regulations for kraft mill sources is a critical element in this analysis. Some 28 states with kraft mills have regulations which vary widely in their effectiveness of reducing TRS emissions. The variability in regulations from state to state has been taken into account in the determination of total industry costs.

Throughout this chapter the terms capital cost and annualized cost are used; therefore, a brief definition is in order. The capital cost includes all the items necessary to design, purchase, and retrofit either a control device or process equipment necessary to achieve the emission reduction. The capital cost includes the purchase of all factory assembled equipment, such as a recovery furnace boiler, black liquor oxidation system components, incinerator, and so forth; ancillary items, such as fans, instrumentation, pumps; equipment installation cost including demolition, site clearance, piping, wiring, and the cost of engineering, construction overhead, and contingencies. Capital costs are reported in third quarter

1976 dollars. The annualized cost of a retrofit project, whether it be a control device or replacement of process equipment, is a measure of what it costs the company to own and operate that system. The annualized cost includes direct operating costs such as labor, utilities and maintenance; and capital related charges such as depreciation, interest, administrative overhead, property taxes, and insurance. The actual costs experienced by individual mills may vary considerably and often are difficult to collect. Nevertheless, attempts must be made to determine reasonable estimates of these costs. The following values were chosen as typical and should provide a reasonable estimate of the annualized costs of the retrofit control requirements. Operating labor is charged at a rate of $6 per hour with supervision at $8 per hour. Electricity is assumed to cost 2.5 cents per kilowatt-hour. Fuel costs are assessed at $2.00 per million BTU. For purposes of estimating annualized costs, 328.5 operating days per year were assumed.

Recovery furnaces and lime kilns that would constitute replacements necessary to achieve TRS reduction are not allocated any charges for maintenance and repair. The reason for this is that such maintenance costs incurred for replacement would be offset by maintenance charges foregone in scrapping the old equipment.

For gas collection and piping systems, including incinerators, maintenance costs are assessed at 2 percent of capital investment. For black liquor oxidation systems and oxygen plants, a charge of 4 percent of capital investment is expensed.

Capital charges have been calculated on the basis of 100 percent debt financing and recovery of capital by uniform periodic payments (capital recovery factor). Rate of interest for institutional lending is assumed to be 10 percent. The economic life assumed for all equipment is 15 years. Property taxes and insurance are assessed at a rate of 2 percent. Administrative overhead costs involving records keeping, monitoring, etc. are also assessed at a rate of 2 percent.

8.2 Methodology

The affected facilities and control systems were previously discussed in Chapter 6. The retrofit control techniques that can achieve the necessary emission reductions, as outlined in Table 6-2, are summarized in Table 8-1 for each affected facility and control system. These control techniques were based on certain assumptions, which reflect the content of information available for estimating retrofit costs. These assumptions will be discussed in detail in the following subsections for each affected facility.

The cost information on retrofit controls for recovery furnaces presented in this chapter applies to cross-recovery furnaces as well as straight kraft recovery systems. However, there is one precaution that should be noted. The application of the control techniques for straight kraft recovery furnaces as discussed here and in Chapter 6 will not necessarily result in the same achievable emission levels for cross-recovery furnaces as reported in this chapter.

For cost estimating purposes, a list of mill characteristics was compiled for each kraft pulp mill in the United States. The information compiled includes kraft production capacity; number, capacity, manufacturer, basis design (direct or indirect contact) and year of manufacture of the recovery furnace; the number and production rate for lime kilns; the number,

Table 8-1. SUMMARY OF RETROFIT CONTROL TECHNIQUES FOR ALTERNATIVE CONTROL SYSTEMS ON EXISTING KRAFT MILLS

	CONTROL SYSTEMS					
SOURCE	1	2	3	4	5	6
Recovery Furnace	a) Replace Furnaces >10 yrs. of age b) Add 2nd Stage Black Liquor Oxidation (Including furnaces <10 yrs. of age). Also improve furnace air distribution	Same as 1	a) Replace Furnaces >20 yrs. of age b) Add 2nd Stage Black liquor oxidation for all other furnaces. Also improve furnace air distribution.	Same as 3	Same as 3	Same as 1
Digester System	Incineration	Incineration	Incineration	Incineration	Incineration	Incineration
Multiple Effect Evaporators	Incineration	Incineration	Incineration	Incineration	Incineration	Incineration
Lime Kiln	a) Increase Lime Mud Washing Capacity b) Increase fan cap. & Monitor Oxygen and temp. (kiln) c) Add caustic to kiln scrubber	Same as 1	Same as 1	a) Increase Lime Mud Washing Capacity b) Increase Fan Cap. & Monitor oxygen & temp(kiln)	a) Increase Fan Cap. & Monitor Oxygen and temp. (Kiln)	Same as 5
Brown Stock Washer System	Incineration	No Control	No Control	No Control	No Control	No Control
Black Liquor Oxidation System Vents	Molecular Oxygen	No Control	No Control	No Control	No Control	No Control
Smelt Dissolving Tank	Substitute fresh water for condensate	Same as 1	Same as 1	Same as 1	Same as 1	Same as 1
Condensate Stripping System	Incineration	Incineration	Incineration	Incineration	Incineration	Incineration

type, and TRS controls for multiple effect evaporators and digesters; and the number of brown stock washing systems and number of washing stages per system. Mill capacity and other data were compiled from Posts'[1] and Lockwoods'[2] directories and updated wherever possible from contacts with pulp and paper companies.

The approach used to estimate retrofit control costs is as follows. The National Council for Air and Stream Improvement (NCASI) was called upon to provide EPA both the contacts within individual paper companies for sources of cost data and the technical parameters, or guidelines,(3) for estimating costs. These guidelines were also made available to industry personnel for estimating costs. The following 8 companies were selected and contacted to provide maximum coverage in terms of mills and capacity:

(a) International Paper
(b) Weyerhaeuser
(c) Georgia Pacific
(d) Westvaco
(e) Boise Cascade
(f) St. Regis
(g) Western Kraft (Willamette Industries)
(h) Mead Corporation

Actual corporate data covering both costs and mill characteristics were provided for 42 mills by these companies. This coverage constitutes 35 percent of the number of total mills and about 41 percent of total U.S. capacity. Two boiler manufacturers, who have built all the kraft recovery furnaces in the U.S.,were contacted to provide information on ages of existing furnaces, as well as the cost of new furnaces. In-house information was used to generate cost estimates, which were then used as a forum for discussion during visits with the corporate staff of the eight paper companies. The time for the data gathering phase was the second quarter of 1975.

The data received from the paper companies were analyzed for regression possibilities with mill characteristics. The next step was to develop model plant costs for the following model mills: 500 tons per day, 1000 tons per day, and 1500 tons per day production capacity. These model plant costs in combination with the information on mill characteristics and furnace age were used to estimate costs for the remaining 65 percent of the mills in the U.S.

8.3 Costs for Affected Facilities

8.3.1 Recovery Furnaces

The major problem from the standpoint of TRS emission in existing kraft mills is associated with the burning of black liquor in direct contact recovery furnaces. The methods used to reduce these emissions are: (1) close monitoring and control of the process variables in the recovery furnace and, (2) oxidizing the black liquor to reduce the sulfides content before evaporation of the black liquor in the direct contact evaporator. Control of the process variables depends significantly upon the original design and configuration of the recovery furnace. Hence, furnace age is a critical factor in determining the extent of retrofit costs.

Recovery furnaces, including both direct contact and indirect contact, of new design - as defined in Chapter 6 - are capable of achieving a 5 ppm level of TRS without any additional costs for process controls, as indicated in Chapter 6. Many of those process controls discussed in Chapter 6, such as flexibility in air distribution and the membrane insulation between wall tubes, are inherently designed in most furnaces constructed since 1965. Mills with a direct contact furnace of the design just mentioned are assumed to incur costs only for a second stage of black liquor oxidation as the requirement for achieving a 5 ppm level of TRS from the total recovery furnace affected facility. Mills with indirect contact furnaces are assumed to achieve the 5 ppm without any additional costs. Note that the indirect contact furnace design concept has been commercially available only since 1967.

Recovery furnaces built prior to 1965 are assumed to be incapable of achieving a 5 ppm level of TRS despite any attempts to achieve the most efficient black liquor oxidation system. The key element in the assumption is related to the earlier design of the furnace itself, which was not conducive toward reduction of TRS to low levels. Therefore, the control strategy for a 5 ppm level would require the replacement of the recovery furnace, which constitutes the retrofit cost. For furnaces built between 1955 and 1965, the 20 ppm level is assumed to be achievable, according to NCASI guidelines and discussion in Chapter 6 . The only costs incurred are those associated with adding a second stage of black liquor oxidation. For furnaces built prior to 1955, the retrofit costs assumed include replacement of the furnace plus a complete 2-stage black liquor oxidation for both the 5 ppm and the 20 ppm control levels. This assumption is in accord with NCASI guidelines.

Another important factor besides age that would affect costs is the need for additional black liquor burning capacity. In particular, mills that have not added a recovery furnace since 1965 may be overloading furnaces with black liquor from a design standpoint. Such a practice leads to high TRS emissions. Mills that have furnaces built between 1955 and 1965 and appear to have underrated furnace capability, according to available data on mill characteristics, are assumed to add additional black liquor burning capacity in order to achieve the 20 ppm strategy. Therefore, such mills would have to purchase a new furnace in order to achieve the 20 ppm level.

Additional guidelines were developed by NCASI to provide these companies technical parameters for black liquor oxidation as a complement to process controls in the recovery furnace toward achieving the 5 ppm and the 20 ppm levels.

The guidelines used for estimating costs of black liquor oxidation requirements are stated as follows. The oxidation system representative of best technology consists of: (a) two-stage oxidation with at least one stage of oxidation, (b) retention time of five hours for both stages combined, (c) stand-by blower capacity, and (d) monitoring of both oxidizing air and liquor flow rates. The NCASI provided these guidelines to each company, which in turn was to assess its requirements relative to their existing oxidation system capabilities.

The costs presented in Table 8-2 for model plants were analytically derived from the results received for some 42 mills. Cost data for recovery furnaces in 17 mills, which management felt may be required, correlated reasonably well with mill size as a parameter. Conversely, data received from various companies for oxidation requirements as to the condition of existing oxidation systems, sulfidity of black liquor, and level of experience acquired with development of highly efficient oxidation systems did not correlate well with mill size. This result occurred despite the specific guidelines set forth by NCASI to the managerial staff of the 8 companies. A probable explanation is that the nature of mill operations and mill lay-out vary widely, which affect costs significantly.

Table 8-2. RETROFIT CONTROL COSTS FOR RECOVERY FURNACES

A. Furnace Replacement(1)

Mill Size, TPD	500	1000	1500
Capital Costs ($)	13,400,000	23,300,000	32,200,000
Annualized Costs ($/Yr.)	2,270,000	4,000,000	5,470,000
Annualized Costs per Ton ($/T)	13.82	12.18	11.09

B. Second Stage Black Liquor Oxidation(2)

Mill Size, TPD	500	1000	1500
Capital Costs ($)	600,000	1,000,000	1,500,000
Annualized Costs ($/Yr.)	153,000	242,000	360,000
Annualized Costs per Ton ($/T)	0.93	0.74	0.73

(1) Control strategy required to achieve 5 ppm for mills whose furnaces were built prior to 1965. Costs include secondary black liquor oxidation.

(2) Control strategy required to achieve 20 ppm for furnaces built since 1955. Pre-1955 furnaces are assumed unable to achieve 20 ppm; require replacement.

8.3.2 Digesters and Multiple Effect Evaporators

The control technique for achieving a 5 ppm level is incineration of the noncondensible TRS compounds emitted from various vents. The nature of the retrofit project involves the collection of the noncondensibles and piping them to the incineration point, as well as necessary upgrading of the blow heat recovery system associated with the digesters. Normally, the incineration point is the lime kiln; however, in some situations, a separate incinerator may be used as the back-up for the lime kiln or as the regular control device.

Data gathered from the selected paper companies did not reveal any significant correlation of cost with mill size. The probable explanation of this are the number of digesters, their spatial arrangement, condition of blow heat recovery system, and type of gas holding system. Despite the weak correlation of costs with capacity estimates were made for model plants to represent three conditions: (1) batch digesters with extensive piping requirements only (low retrofit penalty); (2) batch digesters with extensive piping, refurbished blow heat recovery, and separate incineration; (high retrofit penalty) and (3) continuous digesters. Multiple effect evaporator vents are assumed to be combined with the digester vents for all three cases. The costs for incineration are presented in Table 8-3. Utility requirements for electricity and fuel were developed from data by an engineering construction company.(5) Fuel consumption assumed in Table 8-3 for destruction of noncondensible TRS emissions are based on use of a separate incinerator as a stand-by control device for 33 days, or ten percent of the time. This represents an assumed duration of downtime for the lime kiln for maintenance when the kiln becomes unavailable as a control device for incinerating TRS emissions.

Table 8-3. RETROFIT CONTROL COSTS FOR DIGESTERS AND MULTIPLE EFFECT EVAPORATORS

A. Batch Digesters - Low Retrofit Penalty(1)

Mill Size, TPD	500	1000	1500
Capital Costs ($)	400,000	900,000	1,600,000
Annualized Costs ($/Yr.)	96,000	210,000	360,000
Annualized Costs per Ton ($/T)	0.58	0.64	0.73

B. Batch Digesters - High Retrofit Penalty(2)

Mill Size, TPD	500	1000	1500
Capital Costs ($)	900,000	2,000,000	3,500,000
Annualized Costs ($/Yr.)	207,000	452,000	773,000
Annualized Costs per Ton ($/T)	1.26	1.38	1.57

C. Continuous Digesters

Mill Size	500	1000	1500
Capital Costs ($)	300,000	400,000	500,000
Annualized Costs ($/Yr.)	67,000	96,000	125,000
Annualized Costs per Ton ($/T)	0.41	0.29	0.25

(1) Includes provision for extensive piping only.

(2) Includes blow heat recovery [illegible]tem, extensive piping, separate incinerator.

8.3.3 Brown Stock Washers

The control technique for achieving the 5 ppm level of TRS emissions from washer vents is incineration. The incineration may be carried out either in the recovery furnace or a separate incinerator. As pointed out in Chapter 6, incineration in an existing recovery furnace may restrict the operation of the recovery furnace. The gas flows from the washer system are too great for the lime kiln to incinerate. For some mills, a separate incinerator may be the only available control device to treat the washer vent gases.

Preliminary EPA costs were developed in-house on the basis of ventilation requirements of 100 scfm/TPD, a parameter which is documented in Chapter 6. The basis for estimating hooding and ducting requirements was information provided from NCASI for actual retrofit situations.(6) The capital costs for a separate incinerator were developed from data by the Industrial Gas Cleaning Institute(7) for an incinerator (with heat recovery) application on an asphalt saturator plant. The preliminary EPA costs were dissiminated to the selected group of paper companies for comment. The responses from these companies was assimilated into revision of the estimates, which are presented in Table 8-4.

It must be pointed out that some unusual retrofit problems can occur at specific mills, where hooding brown stock washers may be constrained severely by space limitations. In such mills, demolition of portions of the washing building and reconstruction may be required. In other mills, the washers may have to be replaced with semi-closed drum washers. For these situations, retrofit costs may be much higher than those estimates presented in Table 8-4.

Table 8-4. RETROFIT CONTROL COSTS FOR BROWN STOCK WASHERS

A. Destruction in Separate Incinerator

Mill Size, TPD	500	1000	1500
Capital Costs ($)	1,600,000	2,500,000	3,200,000
Annualized Costs ($/Yr.)	900,000	1,670,000	2,400,000
Annualized Costs per Ton ($/T)	5.48	5.08	4.87

B. Destruction in Recovery Furnace

Mill Size, TPD	500	1000	1500
Capital Costs ($)	900,000	1,500,000	1,900,000
Annualized Costs ($/Yr.)	192,000	326,000	423,000
Annualized Costs Per Ton ($/T)	1.17	0.99	0.86

For separate incineration, a fuel penalty of 1.76 million BTU per ton pulp was used. The basis for this is 22 million BTU per hour for a 30,000 scfm incinerator utilizing primary and secondary heat recovery.(8) Responses from the industry indicated that this fuel penalty is just slightly above the industry average. It should be pointed out that fuel requirements would be sensitive to ventilation rates of the washers, the degree of heat recovery, and use of catalyst to reduce ignition temperature. The use of catalyst was not assumed in the above estimate.

8.3.4 Lime Kilns

Three levels of control are being considered for this affected facility. The level of 40 ppm represents process controls of adding more air and raising the cold-end temperature of the kiln by 100° F. Adding a fan and instrumentation are assumed to be the required cost items. In-house EPA estimates of costs were generated on the basis of available costs for fans and instrumentation. These costs were then reviewed with industry personnel for comparison with actual modification costs for lime kilns.

The level of 20 ppm represents the combination of good lime mud washing and control of the kiln process variables. Costs were provided by companies on the basis of replacing centrifuges with vacuum drum filters and adding another mud washing stage. NCASI guidelines(9) for cost estimating purposes were approximately 0.5 ft^2/ton pulp for filtration and 12 to 21 hours of retention in the clarifier stage.

The level of 8 ppm represents the addition of caustic to the lime kiln scrubber as a complement to the aforementioned requirements for achieving 8 ppm. The costs for caustic addition are assumed to be the same as those reported in the Standards Support and Environmental Impact Statement.(10)

The capital and annualized costs for the three control levels are presented in Table 8-5. There are three points concerning Table 8-5 that should be discussed. First, the fuel penalty assumed in the annualized costs for process controls was based on use of 142 million BTU fuel for a 1000 ton per day mill. This is the enthalpy requirement to raise the cold-end temperature of the kiln 100° F. Second, either process controls or combined process controls with mud washing may not achieve the 40 ppm level. In this circumstance, the mill may be short on lime burning capacity and would have to add another lime kiln unit. Results from surveying the industry indicate that a kiln addition in the range of 160-200 TPD (CaO basis) seemed typical, regardless of mill size. Capital costs for the kiln are $3 million; and annualized costs, $510,000. For this mill, the kiln addition plus process controls on the existing kiln would be the requirement to achieve 40 ppm.

Lastly, the costs in Table 8-5 are presented to demonstrate retrofit problems with mud washing. Results from the industry survey varied widely. To take account of this, costs were estimated for a low retrofit and a high retrofit case. Some of the problems associated with high retrofit costs may be related to space limitation, replacement of the entire washing system, or changing condensate wash water to fresh water by addition of a condensate stripper.

8.3.5 Black Liquor Oxidation Vents

The control techniques for achieving the 5 ppm level of TRS emissions from black liquor oxidation system vents are incineration and the use of molecular oxygen for oxidation. The vent gases may be combined with the brown stock washer vents and destroyed in the recovery furnace or separate

Table 8-5. RETROFIT CONTROL COSTS FOR LIME KILNS

A. Process Controls(1)

Mill Size, TPD	500	1000	1500
Capital Costs ($)	75,000	100,000	200,000
Annualized Costs ($/Yr.)	54,000	107,000	175,000
Annualized Costs per Ton ($/T)	0.33	0.33	0.36

B. Mud Washing Capacity - Low Retrofit Penalty(2)

Mill Size, TPD	500	1000	1500
Capital Costs ($)	480,000	730,000	950,000
Annualized Costs ($/Yr.)	91,200	139,000	181,000
Annualized Costs per Ton ($/T)	0.56	0.42	0.37

C. Mud Washing Capacity - High Retrofit Penalty(3)

Mill Size, TPD	500	1000	1500
Capital Costs ($)	960,000	1,460,000	1,900,000
Annualized Costs ($/Yr.)	182,000	278,000	362,000
Annualized Costs per Ton ($/T)	1.11	0.85	0.73

D. Caustic Addition

Mill Size, TPD	500	1000	1500
Capital Costs ($)	-0-	-0-	-0-
Annualized Costs ($/Yr.)	3000	6000	9000
Annualized Costs per Ton ($/T)	0.02	0.02	0.02

(1) In some situations, mills may be short on lime burning capacity. Typical capacity requirements might be on the order of 160 to 200 TPD CaO, which was fouund to be independent of mill size. Capital costs would be $3 million; annualized costs of $510,000 per year.

(2) Includes only additional filtration and clarifier capacity.

(3) Includes condensate stripper for removal of TRS from water used for mud washing and/or charges for space limitation.

incinerator. However, incineration costs for the BLO vents will be considered separately from the brown stock washers.

Costs for incineration in recovery furnaces were taken from the costs developed for new sources.(11) Very few responses were received from industry, but one company did report similar costs,(12) which were found to be comparable with EPA estimates. Costs for separate incinerators were developed on the basis of a 26,000 scfm incinerator required for a 1000 ton per day mill. The source of the basic cost information was information provided by the Industrial Gas Cleaning Institute.(13) Costs for a 500 ton per day and 1500 ton per day were developed by using a scale factor of 0.3. Fuel requirements were calculated to be 19 million BTU per hour for the 26,000 scfm incinerator on the basis of using primary and secondary heat recovery. No costs for separate incineration were reported from industry.

Costs for molecular oxygen were developed on the basis of 45 tons oxygen per 800 ton pulp produced.(14) Capital costs for skid-mounted low-pressure oxygen plants were obtained from Airco, Inc. (15) The energy consumption for use of molecular oxygen is assumed to be 20 kilowatt-hours per ton of pulp, or 380 kilowatt-hours per ton of oxygen produced.(16)

A summary of capital and annualized costs for control of black liquor oxidation vents is presented in Table 8-6. The costs for incineration in a recovery furnace should reflect minimal retrofit problems. On the other hand, separate incineration and molecular oxygen should represent high retrofit costs.

8.3.6 Smelt Dissolving Tank

The control strategy for achieving 8 ppm is the use of fresh water in a scrubber. This scrubber should already be installed in most mills because of state regulations for controlling particulates. The use of fresh water

Table 8-6. RETROFIT CONTROL COSTS FOR BLACK LIQUOR OXIDATION VENTS

A. Destruction in Recovery Furnace

Mill Size, TPD	500	1000	1500
Capital Costs ($)	220,000	330,000	432,000
Annualized Costs ($/Yr.)	60,000	96,000	133,000
Annualized Costs per Ton ($/T)	0.37	0.29	0.27

B. Destruction in Separate Incinerator

Mill Size, TPD	500	1000	1500
Capital Costs ($)	400,000	560,000	700,000
Annualized Costs ($/Yr.)	233,000	420,000	605,000
Annualized Costs per Ton ($/T)	1.42	1.28	1.23

C. Molecular Oxygen

Mill Size, TPD	500	1000	1500
Capital Costs ($)	1,080,000	1,640,000	2,100,000
Annualized Costs ($/Yr.)	309,000	509,000	645,000
Annualized Costs per Ton ($/T)	1.88	1.55	1.31

is the only additional requirement which may be needed to reduce the TRS effectively.

It is expected that costs associated with use of fresh water will be small. During the survey, one company provided cost data for installing particulate scrubbers on this affected facility on one mill. Other than this example, no other company reported any cost for substituting fresh water for process water with high sulfides content.

8.3.7 Condensate Strippers

The control technique for achieving the 5 ppm level is incineration in the lime kiln for steam stripping and incineration in the recovery furnace for air stripping. Only five mills in the U.S. presently employ condensate strippers. Four of these mills are presently incinerating condensate stripper vents.

Those mills that may decide to install condensate strippers in the future are assumed to incur costs similar to reported costs for new sources.(17) Those costs which are in 1976 dollars are summarized in Table 8-7. These costs include a fan, duct, seal pot, and flame arrester with the incineration point being the lime kiln. No retrofit penalty has been assigned because there are very few condensate strippers in existing mills. Future controls for new strippers should incur minimal retrofit costs. However, it still is possible that some retrofit penalty could be incurred if prior provisions have not been made to tap into the mill's piping system for venting other noncondensibles to an incineration point within the mill.

Table 8-7. CONTROL COSTS FOR CONDENSATE STRIPPER

Mill Size, TPD	500	1000	1500
Capital Cost ($)	16,200	22,700	28,100
Annualized Costs ($/Yr.)	6,300	7,800	8,900
Annualized Costs per Ton ($/T)	0.04	0.02	0.02

8.4 Incremental Costs For Model Mills

The purpose of this section is to present incremental control costs over requirements for state regulations, on a total mill basis. To take into account the interrelationships involved with the many significant factors in estimation of retrofit costs, three model mill situations will be utilized to depict costs. These model situations are described as follows:

(1) a post-1965 modern mill

(2) an old (pre-1965) mill with low retrofit penalty

(3) an old (pre-1965) mill with high retrofit penalty

The modern mill has a recovery furnace of modern design that can achieve the 5 ppm level under good operating conditions. The black liquor burning unit may be either a direct contact furnace or an indirect contact furnace. The latter type of furnace has been installed in mills only since 1967. Only the direct contact furnace will incur any control costs, which will be for secondary black liquor oxidation to assure achievement of the 5 ppm level. As for as the remaining affected facilities, only low retrofit costs are assumed to be incurred.

The old mill built before 1965, with low retrofit penalty, is assumed to have a recovery furnace(s) capable of achieving the 20 ppm level. Furnace replacement costs would be incurred only for a 5 ppm system. On the remaining affected facilities, low retrofit costs would be associated with addition of controls.

The old mill built before 1965, with a high retrofit penalty, is assumed to have a recovery furnace(s) that cannot achieve the 20 ppm level. This may be due to a very old furnace, greater than 20 years of age, or insufficient black liquor burning capacity. The result of this condition is that a new furnace will be required for all control systems. The remaining affected facilities will incur high retrofit costs with the addition of control.

The next important factor influencing incremental costs is the variability in state regulations. Some states with pulp mills have no emission control regulations for existing sources. One set of costs will be presented for such states. Many states with pulp mills have regulations which call for controls on existing recovery furnaces and incineration of noncondensible gases from miscellaneous sources such as digesters, multiple effect evaporators, and condensate strippers. Another set of incremental costs will be presented for such states. Very few states, perhaps one or two, require controls on existing lime kilns, and no states require controls on existing brown stock washers and black liquor oxidation system vents.

Tables 8-8 and 8-9 present incremental costs for a modern mill under the two regulatory situations as described earlier. Capital and annualized costs are presented for the six alternative control systems detailed in Table 8-1. Costs are presented for the direct contact and indirect contact recovery furnace designs. For brown stock washers and black liquor oxidation system vents, costs are presented only for destruction in a separate incineration. Destruction of TRS in the recovery furnace may not be widely applicable due to attendant problems of inflexibility and possible explosions, as pointed out in Chapter 6.

Where no regulations exist (Table 8-8), incremental annualized control costs for the model mill with the direct contact recovery furnace range from $1.73 per ton for control system 6 to $8.53 per ton for system 1. For

Table 8-8. INCREMENTAL RETROFIT CONTROL COSTS FOR A 1000 TPD MODERN MILL (BUILT AFTER 1965)
Location: State with No Regulations

	No. 1			No. 2			No. 3		
	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)
A. Recovery Furnace									
a) Direct Contact	1,000	242	0.74	1,000	242	0.74	1,000	242	0.74
b) Indirect Contact	0	0	0	0	0	0	0	0	0
B. Batch Digester and(1) Multiple Effect Evaporator	900	210	0.64	900	210	0.64	900	210	0.64
C. Brown Stock Washers(2)	2,500	1,670	5.08	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents(2) (Direct Contact Only)	560	420	1.28	0	0	0	0	0	0
E. Lime Kiln(3)	830	252	0.77	830	252	0.77	830	252	0.77
F. Condensate Stripper	23	8	0.02	23	8	0.02	23	8	0.02
TOTAL COSTS									
a) Direct Contact	5,813	2,802	8.53	2,753	712	2.17	2,753	712	2.17
b) Indirect Contact	4,253	2,140	6.51	1,753	470	1.43	1,753	470	1.43

	No. 4			No. 5			No. 6		
A. Recovery Furnace									
a) Direct Contact	1,000	242	0.74	1,000	242	0.74	1,000	242	0.74
b) Indirect Contact	0	0	0	0	0	0	0	0	0
B. Batch Digester and(1) Multiple Effect Evaporator	900	210	0.64	900	210	0.64	900	210	0.64
C. Brown Stock Washers(2)	0	0	0	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents(2) (Direct Contact Only)	0	0	0	0	0	0	0	0	0
E. Lime Kiln(3)	830	246	0.75	100	107	0.33	100	107	0.33
F. Condensate Stripper	23	8	0.02	23	8	0.02	23	8	0.02
TOTAL COSTS									
a) Direct Contact	2,753	706	2.15	2,023	567	1.73	2,023	567	1.73
b) Indirect Contact	1,753	464	1.41	1,023	325	0.99	1,023	325	0.99

(1) Low retrofit penalty
(2) Destruction in separate incinerator
(3) Low retrofit penalty

Table 8-9. INCREMENTAL RETROFIT CONTROL COSTS FOR A 1000 TPD MODERN MILL (BUILT AFTER 1965)
Location: State with Typical Regulations(1)

	No. 1			No. 2			No. 3		
	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)
A. Recovery Furnace									
a) Direct Contact	1,000	242	0.74	1,000	242	0.74	0	0	0
b) Indirect Contact	0	0	0	0	0	0	0	0	0
B. Batch Digesters and Multiple Effect Evaporator	0	0	0	0	0	0	0	0	0
C. Brown Stock Washers(2)	2,500	1,670	5.08	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents(2) (Direct Contact Only)	560	420	1.28	0	0	0	0	0	0
E. Lime Kiln(3)	830	252	0.77	830	252	0.77	830	252	0.77
F. Condensate Stripper	0	0	0	0	0	0	0	0	0
TOTAL COSTS									
a) Direct Contact	4,890	2,584	7.87	1,830	494	1.50	830	252	0.77
b) Indirect Contact	3,330	1,922	5.85	830	252	0.77	830	252	0.77

	No. 4			No. 5			No. 6		
A. Recovery Furnace									
a) Direct Contact	0	0	0	0	0	0	1,000	242	0.74
b) Indirect Contact	0	0	0	0	0	0	0	0	0
B. Batch Digester and Multiple Effect Evaporator	0	0	0	0	0	0	0	0	0
C. Brown Stock Washers(2)	0	0	0	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents(2) (Direct Contact Only)	0	0	0	0	0	0	0	0	0
E. Lime Kiln(3)	830	246	0.75	100	107	0.33	100	107	0.33
F. Condensate Stripper	0	0	0	0	0	0	0	0	0
TOTAL COSTS									
a) Direct Contact	830	246	0.75	100	107	0.33	1,100	349	1.07
b) Indirect Contact	830	246	0.75	100	107	0.33	100	107	0.33

(1) A typical state is assumed to require 20 ppm for the recovery furnace and incineration (5 ppm) of TRS emissions from digesters, multiple effect evaporators, and condensate strippers.

(2) Destruction in separate incinerator.

(3) Low retrofit penalty

the indirect contact furnace, the model mill incurs incremental annualized control costs ranging from $0.99 per ton for system 6 to $6.51 per ton for system 1. In states with the typical composite of regulations (Table 8-9), incremental annualized control costs range from $1.07 per ton for system 6 to $7.87 per ton for system 1 in a mill with a direct contact furnace. For the mill with the indirect contact furnace, incremental annualized costs for these respective systems range from $0.33 per ton to $5.85 per ton.

For modern mills, the most significant cost is that associated with incineration of brown stock washer gases. The control of this affected facility alone is $5.08 per ton for system 1 (Table 8-8 and 8-9) of which $3.50 per ton is a fuel penalty. The fuel penalty would not be incurred in some mills where the washer gases can be incinerated in a recovery furnace. It should be noted that the rather significant $1.28 per ton cost for controlling black liquor oxidation system vents only occurs for the mill with a direct contact furnace.

Tables 8-10 and 8-11 present control costs for an old mill with a low retrofit penalty. Capital and annualized costs are presented for the six alternative control systems detailed in Table 8-1. The costs for control of brown stock washers and black liquor oxidation system vents is based on separate incineration. The replacement of the recovery furnace is assumed to be required for systems 1, 2, and 6. Furthermore, the furnace is assumed to have ample capacity to support the mill's normal production needs. This assumption eliminates any consideration of additional furnace investment for systems 3, 4, and 5.

Where no state regulations exist (Table 8-10), incremental annualized

Table 8-10. INCREMENTAL RETROFIT CONTROL COSTS FOR A 1000 TPD OLD MILL (BUILT BEFORE 1965) - LOW RETROFIT PENALTY
Location: State with No Regulations

	No. 1			No. 2			No. 3		
	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)
A. Recovery Furnace(1)	23,300	4,000	12.18	23,300	4,000	12.18	1,000	242	0.74
B. Batch Digester and Multiple Effect Evaporators	900	210	0.64	900	210	0.64	900	210	0.64
C. Brown Stock Washers(2)	2,500	1,670	5.08	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents (2)	560	420	1.28	0	0	0	0	0	0
E. Lime Kiln	830	252	0.77	830	252	0.77	830	252	0.77
F. Condensate Stripper	23	8	0.02	23	8	0.02	23	8	0.02
TOTAL COSTS	28,113	6,560	19.97	25,053	4,470	13.61	2,753	712	2.17

	No. 4			No. 5			No. 6		
A. Recovery Furnace(1)	1,000	242	0.74	1,000	242	0.74	23,300	4,000	12.18
B. Batch Digester and Multiple Effect Evaporators	900	210	0.64	900	210	0.64	900	210	0.64
C. Brown Stock Washers(2)	0	0	0	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents(2)	0	0	0	0	0	0	0	0	0
E. Lime Kiln	830	246	0.75	100	107	0.33	100	107	0.33
F. Condensate Stripper	23	8	0.02	23	8	0.02	23	8	0.02
TOTAL COSTS	2,753	706	2.15	2,023	567	1.73	24,323	4,325	13.17

(1) Recovery furnace would be a direct contact furnace only

(2) Destruction in separate incinerator

Table 8-11. INCREMENTAL RETROFIT CONTROL COSTS FOR A 1000 TPD OLD MILL (BUILT BEFORE 1965) - LOW RETROFIT PENALTY
Location: State with Typical Regulations(1)

	No. 1			No. 2			No. 3		
	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)
A. Recovery Furnace	23,300	4,000	12.18	23,300	4,000	12.18	0	0	0
B. Batch Digesters and Multiple Effect Evaporators	0	0	0	0	0	0	0	0	0
C. Brown Stock Washers(2)	2,500	1,670	5.08	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents(2)	560	420	1.28	0	0	0	0	0	0
E. Lime Kiln	830	252	0.77	830	252	0.77	830	252	0.77
F. Condensate Stripper	0	0	0	0	0	0	0	0	0
TOTAL COSTS	27,190	6,342	19.31	24,130	4,252	12.95	830	252	0.77

	No. 4			No. 5			No. 6		
	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)
A. Recovery Furnace	0	0	0	0	0	0	23,300	4,000	12.18
B. Batch Digesters and Multiple Effect Evaporators	0	0	0	0	0	0	0	0	0
C. Brown Stock Washers(2)	0	0	0	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents(2)	0	0	0	0	0	0	0	0	0
E. Lime Kiln	830	246	0.75	100	107	0.33	100	107	0.33
F. Condensate Stripper	0	0	0	0	0	0	0	0	0
TOTAL COSTS	830	246	0.75	100	107	0.33	23,400	4,107	12.51

(1) A typical state is assumed to require 20 ppm for the recovery furnace and incineration (5 ppm) of TRS emissions from digesters, multiple effect evaporators, and condensate strippers

(2) Destruction in separate incinerator.

costs range from $1.73 per ton to $2.17 per ton for systems 3, 4, and 5. The incremental annualized costs for systems 1, 2, and 6 range from $13.17 to $19.97 per ton. The replacement of the recovery furnace is responsible for $12.18 per ton of these costs.

In a state with typical regulations, incremental annualized costs range from $0.33 to $0.77 per ton for systems 3, 4, and 5. For systems 1, 2, and 6, incremental annualized costs range from $12.51 per ton to $19.31 per ton, the most expensive being system 1. Again, recovery furnace replacement is responsible for $12.18 per ton.

Tables 8-12 and 8-13 present control costs for the old model mill with the incidental high retrofit penalty. Capital and annualized costs are presented for the six alternative control systems similar to the previous models. Costs of control for the washer gases and the oxidation vents is based on separate incineration. The construction of new furnace sized to support the entire 1000 ton per day mill is assumed in the cost estimates for: (1) all control systems in states with no regulations, and (2) control systems 1, 2, and 6 in states with typical regulations. The aspects of the high retrofit costs for this model mill involve the controlling of the digestors/evaporators and the lime kiln. The two factors associated with the lime kiln, namely additional requirements for lime mud washing and additional lime burning capacity, have been taken into account for this model mill. In summary, Table 8-12 would represent the worst situation - - an old mill with incidental high retrofit penalties in a state with no regulations.

Where no regulations exist (Table 8-12), incremental annualized costs range from $15.46 per ton for system 6 to $22.68 per ton for system 1. New furnace costs are responsible for $12.18 per ton of these costs. In

Table 8-12. INCREMENTAL RETROFIT CONTROL COSTS FOR A 1000 TPD OLD MILL (BUILT BEFORE 1965) - HIGH RETROFIT PENALTY
Location: State With No Regulations

	No. 1			No. 2			No. 3		
	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)
A. Recovery Furnace[(1)]	23,300	4,000	12.18	23,300	4,000	12.18	23,300	4,000	12.18
B. Batch Digester and Multiple Effect Evaporator	2,000	452	1.38	2,000	452	1.38	2,000	452	1.38
C. Brown Stock Washers[(2)]	2,500	1,670	5.08	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents[(2)]	560	420	1.28	0	0	0	0	0	0
E. Lime Kiln[(3)]	4,560	901	2.74	4,560	901	2.74	4,560	901	2.74
F. Condensate Stripper	23	8	0.02	23	8	0.02	23	8	0.02
TOTAL COSTS	32,943	7,451	22.68	29,883	5,361	16.32	29,883	5,361	16.32
	No. 4			No. 5			No. 6		
A. Recovery Furnace	23,300	4,000	12.18	23,300	4,000	12.18	23,300	4,000	12.18
B. Batch Digester and Multiple Effect Evaporator	2,000	452	1.38	2,000	452	1.38	2,000	452	1.38
C. Brown Stock Washers[(2)]	0	0	0	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents[(2)]	0	0	0	0	0	0	0	0	0
E. Lime Kiln[(3)]	4,560	896	2.73	3,100	617	1.88	3,100	617	1.88
F. Condensate Stripper	23	8	0.02	23	8	0.02	23	8	0.02
TOTAL COSTS	29,883	5,355	16.30	28,407	5,077	15.46	28,407	5,077	15.46

(1) Recovery furnace - direct contact only. Furnace with an assumed age exceeding twenty years would have to be replaced for each control strategy.

(2) Destruction in separate incinerator.

(3) High retrofit expenditures for the following: addition of a new lime kiln for each control strategy and addition of condensate stripper for strategy numbers 1 through 4.

Table 8-13. INCREMENTAL RETROFIT CONTROL COSTS FOR A 1000 TPD OLD MILL (BUILT BEFORE 1965) - HIGH RETROFIT PENALTY
Location: State with Typical Regulations(1)

	No. 1			No. 2			No. 3		
	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)
A. Recovery Furnace	23,300	4,000	12.18	23,300	4,000	12.18	0	0	0
B. Batch Digester and Multiple Effect Evaporators	0	0	0	0	0	0	0	0	0
C. Brown Stock Washers(2)	2,500	1,670	5.08	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents(2)	560	420	1.28	0	0	0	0	0	0
E. Lime Kiln(3)	4,560	901	2.74	4,560	901	2.74	4,560	901	2.74
F. Condensate Stripper	0	0	0	0	0	0	0	0	0
TOTAL COSTS	30,920	6,991	21.28	27,860	4,901	14.92	4,560	901	2.74

	No. 4			No. 5			No. 6		
	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)	Capital Costs ($1000)	Annualized Costs ($1000/yr)	Unit Annualized Costs ($/T)
A. Recovery Furnace	0	0	0	0	0	0	23,300	4,000	12.18
B. Batch Digester and Multiple Effect Evaporators	0	0	0	0	0	0	0	0	0
C. Brown Stock Washers(2)	0	0	0	0	0	0	0	0	0
D. Black Liquor Oxidation System Vents(2)	0	0	0	0	0	0	0	0	0
E. Lime Kiln(3)	4,560	896	2.73	3,100	617	1.88	3,100	617	1.88
F. Condensate Stripper	0	0	0	0	0	0	0	0	0
TOTAL COSTS	4,560	896	2.73	3,100	617	1.88	26,400	4,617	14.06

(1) A typical state is assumed to require 20 ppm for the recovery furnace and incineration (5 ppm) of TRS emissions from digesters, multiple effect evaporators, and condensate strippers.
(2) Destruction in separate incinerator
(3) High retrofit expenditures for the following: addition of a new lime kiln for each control system and addition of condensate stripper for system numbers 1 through 4.

states with typical regulations, the incremental annualized costs range from $14.06 per ton to $21.28 per ton for control systems 1, 2, and 6, with system 1 being most expensive. For control systems 3, 4, and 5, the incremental annualized costs range from $1.88 per ton to $2.74 per ton.

From the previous discussion on old mills, the most significant factor that frequently re-appears in the total mill costs has been requirements for new recovery furnace investment. Up to this point all capital related charges associated with purchasing, installing, and ownership of the recovery furnace have been presented as control costs. However, the recovery furnace is a productive capital asset in the sense that it contributes to the economics of pulp production with recovery of energy and chemicals. Consequently, some credit for a productive asset should be deducted from the control costs. However, it is very difficult to estimate this credit on a source by source basis in terms of dollars per ton. Therefore, no credit was deducted.

The extent of credit to be deductible is very source specific. The amount of credit would depend on the remaining economic life of existing furnace equipment. In a specific mill the recovery furnace could be very old, like thirty years of age, and very inefficient. Such a mill would probably be scheduling for the replacement of the old furnace in the near future. Here, the replacement cost should be treated as a normal productive asset with no credit given for control costs. In another mill, a recovery furnace may have a significant amount of residual economic life, say 15 years. Suppose a state should require a 5 ppm level which would force the scrapping and replacement of this recovery furnace. In this situation, the capital value foregone in scrapping the furnace should be the approximate control cost.

In a similar vein, mills that tend to overload recovery furnaces may be required to provide additional black liquor burning capacity to reduce TRS emissions. The incremental capacity sufficient to reduce the emissions to a satisfactory level should be the approximate control cost although a mill would install a complete new recovery unit which would exceed the necessary incremental capacity.

8.5 Aggregate Costs For Industry

In this section the estimated incremental control costs are reported for the existing kraft pulp industry for the six alternative emission control systems outlined in Table 8-1. The approach used was to estimate these costs for each individual mill on the basis of the best technical information available for each mill regarding production rates, furnace capacity and age, type of controls used, status of state regulations, and other technical parameters. Section 8.3, Costs For Affected Facilities, which relates control costs as a function of mill size was used to make the estimates. The model mill approach as outlined in Section 8.4 was not considered suitable to estimate total industry costs because of the wide variability in mill characteristics and state regulatory requirements. However, the two approaches should give consistent results. Verification of the model mill approach with the results obtained by the individual mill approach does support this claim.

Actual cost information received from 42 mills during the EPA industry survey was used to derive the Section 8.3 costs. From these costs, estimates of capital and annualized were made individually for 77 mills which were not contacted in the industry survey. The costs for these mills were then combined with the actual costs received for the 42 surveyed mills to derive industry totals.

The summary of industry incremental costs are reported in Table 8-14 for each system. Capital and annualized costs are presented for industry totals and on a unit basis. In addition, incremental capital costs are related to mill investment as a measured percentage. The investment for a battery limits mill is $150 million in 1976 dollars, which was derived from a study for EPA's Office of Solid Waste Management.(18) Similarly, incremental annualized costs are related to the market pulp price as a measured percentage. The price used was $330, which is the currently quoted contract price for domestic bleached kraft pulp.(19) This price represents the average of pulps derived from hard and softwoods.

The industry-wide incremental annualized control costs range from $1.99 per ton for system 5 to $12.72 per ton for system 1. The $1.99 per ton figure is predicated on the basis of replacement of 18 recovery furnaces and 3 lime kilns. The $12.72 per ton figure is predicated on the basis of replacement of 63 recovery furnaces and 33 lime kilns. It should be noted that systems 3 and 4 would require replacement of 18 recovery furnaces and 33 lime kilns. The corresponding percentages in relation to market pulp price are 0.6 percent for system 5 ($1.99 per ton) and 3.9 percent for system 1 ($12.72 per ton).

Capital requirements for incremental controls range from $10.32 per ton capacity for system 5 to $46.20 per ton for system 1. In relation to requirements for new mill investment, these estimates amount to 1.8 percent for system 5 and 8.1 per cent for system 1.

The approach used to develop industry-wide costs represents a composite

Table 8-14. Summary of Industry Incremental Control Costs for Six Alternatives Control Strategies

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Total Capital ($1000)	1,602,000	1,275,000	495,000	495,000	358,000	1,148,000
Capital, per ton capacity ($/T)	46.20	36.78	14.27	14.27	10.32	33.11
Capital, as a percent of new mill(1)	8.1	6.5	2.5	2.5	1.8	5.8
Total Annualized Costs ($1000/yr)	441,000	237,000	94,300	93,600	69,000	200,000
Unit Annualized Costs ($/T)	12.72	6.84	2.72	2.70	1.99	5.76
Annualized costs, as a percent of market pulp price (2)	3.9	2.1	0.8	0.8	0.6	1.7

(1) Capital Costs for New Battery Limits 800 TPD Mill is $150 million, or $570 per ton (1976 dollars) Source: Arthur D. Little, Reference 18.

(2) Market pulp price is $330 per ton, based on fourth quarter 1976 prices for domestic kraft bleached pulp. Source: Paper Trade Journal.

of many different types of state regulations and the individual character of 119 mills. Although the model mill approach in Section 8.4 was considered inappropriate to estimate industry costs, there should be some linkage between the industry-wide costs and the model mill costs on a unit basis. A comparison of the two approaches revealed that the industry-wide costs in Table 8-14 fall about midway between cost requirements for a modern mill in a state with typical regulations (Table 8-9) and for an old mill with low retrofit penalty in a state with no regulations (Table 8-10) for systems 1, 2, and 6. Industry-wide costs in Table 8-14 are somewhat higher than the costs reported for an old mill (Table 8-10) for systems 3, 4, and 5. A conclusion would be that there is some reasonable agreement in the magnitude of the costs developed from the two separate approaches.

8.6 Cost-Effectiveness

An analysis was made to evaluate the cost-effectiveness of the six alternative emission control systems in terms of their contribution to reducing national TRS emissions. The cost-effectiveness technique is a useful tool in selecting an appropriate control system as a recommended guideline. In this selection, those control systems that have significantly high control costs in terms of their pollutant removal are rejected as viable control recommendations. It should be strongly emphasized that the cost-effectiveness approach for recommending controls is only applicable for welfare-related 111-d pollutants, such as TRS. For health-related 111-d pollutants, an economic impact analysis is a requirement for determining affordability of best controls.

The industry aggregate annualized control costs presented in Table 8-14 and the national emission reduction data reported in Table 9-2 were used to make the cost-effectiveness calculations. The results are presented in Table 8-15. The control systems are ranked in ascending order in terms of emission reduction and costs, starting with system 5 as the least expensive. Two calculations of cost-effectiveness are presented for each control system in columns (E) and (F). The calculation in column (E) simply represents the costs per ton removed by a particular control system. The calculation in column (F) represents the marginal costs per ton removed by a particular control system relative to a system of lower ranking. The marginal cost calculation is a more sensitive indicator in revealing the more expensive control system. For example, in Table 8-15, system 6 costs $75,500 per ton marginally. This is much more significant than the $1750 for system 3 or $11,180 for system 4. With respect to actual cost per ton, system 6 costs $3000 per ton, which is significantly higher, to a lesser degree, than the approximate $1400 per ton for systems 4 and 3.

Based on the data in Table 8-15, it would seem reasonable to reject control systems 6, 2, and 1 as not being cost-effective. System 5 might be considered a minimal strategy, costing $1060 per ton. Control systems 4 and 3 cost somewhat more, about $1400 per ton, which would not seem to be of such a magnitude to preclude consideration of these control systems as a viable control technology.

Table 8-15. COST EFFECTIVENESS DATA FOR ALTERNATIVE CONTROL SYSTEMS

Control System	A National Emission Reduction tons/yr.	B Marginal Emission Reduction tons/yr.	C Industry Annualized Control Costs $1000/yr	D Marginal Annualized Control Costs $1000/yr.	E Annualized Costs per ton Removed (C)÷(A), ($/ton)	F Marginal Annualized Cost per ton Removed (D)÷(B),$/ton
5	65,000	65,000	69,000	69,000	1,060	1,060
4	67,200	2,200	93,600	24,600	1,390	11,180
3	67,600	400	94,300	700	1,395	1,750
6	69,000	1,400	200,000	105,700	3,000	75,500
2	71,500	2,500	237,000	37,000	3,315	14,800
1	77,700	6,200	441,000	204,000	5,675	32,900

References for Chapter 8

1. Post's 1973 Pulp and Paper Directory,Miller Freeman Publications, Inc., San Francisco.

2. Lockwood's Directory of the Paper and Allied Trades, Lockwood Publishing Co., New York, 1974.

3. Correspondence from Mr. Russell Blosser, National Council for Air and Stream Improvement, Inc., to Mr. Frank L. Bunyard, EPA, OAQPS, April 22, 1975.

4. See Reference 3.

5. Correspondence from Mr. C. T. Tolar, Rust Engineering Co., Birmingham, Ala., to Mr. Paul A. Boys, October 20, 1972.

6. Correspondence from Mr. Russell Blosser, National Council for Air and Stream Improvement, Inc., to Mr. Paul A. Boys, November 17, 1972.

7. Air Pollution Control Technology and Costs: Seven Selected Emission Sources, Industrial Gas Cleaning Institute, EPA-450/3-74-060, National Technical Information Service, Springfield, Va., December, 1974.

8. Report of Fuel Requirements, Capital Cost and Operating Expense for Catalytic and Thermal Afterburners, CE Air Preheater for Industrial Gas Cleaning Institute, EPA-450/3-76-031, National Technical Information Service, Springfield, Va., September 1976.

9. See Reference 3.

10. Standards Support and Environmental Impact Statement - Volume I: Proposed Standards of Performance for Kraft Pulp Mills, EPA-450/2-76-014a National Technical Information Service, Springfield, Va., September 1976.

11. See reference 10.

12. Correspondence from Mr. Joe Kolberg, Boise Cascade, to Mr. Frank L. Bunyard, OAQPS, EPA, May 1975.

13. See reference 8.

14. See reference 5.

15. Telephone conversation from F. L. Bunyard, OAQPS, EPA, to George Horvat, Airco, Inc., December 30, 1974.

16. Investment and Operating Cost Data for Low Pressure Oxygen Plant Applicability to Non-Ferrous Metallurgy, Volcan - Cincinnati, EPA Contract No. 68-02-2099, Task No. 2, September 29, 1972.

17. See reference 10.

18. *Analysis of Demand and Supply for Secondary Fiber in the U.S. Paper and Paperboard Industry*, Volume 2: Section IX - Process Economics, Arthur D. Little Report for Contract #68-01-02220, Environmental Protection Agency, Office of Solid Waste Management Programs, March, 1975.

19. *Paper Trade Journal*, January 1, 1977.

9. ENVIRONMENTAL IMPACT OF TRS CONTROLS

The environmental impacts discussed are for each of the control techniques and control systems mentioned in Chapter 6. This includes discussions on the impacts on air, water, and solid waste pollution and energy consumption for a relatively large kraft pulp mill (907 megagrams of pulp per day) and on a national basis.

9.1 AIR POLLUTION IMPACT

9.1.1 Annual Air Emission Reductions

Installation of the various control techniques described in Section 6.1 are estimated to reduce TRS emissions from the existing kraft industry by the amounts indicated in Table 9-1. Emission reductions range from 20.6 percent for digester systems to 96 to 97 percent for digester systems and lime kiln systems. All values presented in Table 9-1 are based on information presented in Chapters 5 and 6 and Appendix A of this study.

The following procedure was used to arrive at the numbers listed in Table 9-1. The values listed in Column 2 (Current National Average Emission Rate) were previously mentioned in Chapter 5 and are based on the information listed in Appendix A. Information in Appendix A is based upon discussions with various kraft pulp mills and state control agencies. Column 5 presents the percentage of existing facilities presently using the control techniques described in Column 2 as based on the information listed in Appendix A. The values in Column 6 were developed by applying the emission level achievable by

TABLE 9-1

ENVIRONMENTAL IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES IN A KRAFT MILL

Source	Current Average National Emission g/Kg ADP	(#T ADP)	Control Technique	Emission Level Achievable With Control Technique g/Kg ADP	(# T/ADP)	% of Capacity Not Presently Achieving This Level	Estimated Average National Emission If Control Technique is Required g/Kg ADP	(# T/ADP)	% Emission Reduction Achieved Nationally	National Emission Reduction Mg/year	(tons/year)
Recovery Furnace	1.25	(2.5)	BLO (20 ppm)	0.31	(0.6)	35.7	0.25	(0.5)	80.0	31,200	(34,400)
	1.25	(2.5)	BLO (5 ppm)	0.08	(0.15)	86.9	0.08	(0.15)	94.0	36,690	(40,450)
Digester	0.32	(0.64)	Scrubber	0.59	(1.17)	41.8	0.26	(0.51)	20.6	2,040	(2,250)
	0.32	(0.64)	Incineration	0.01	(0.02)	42.4	0.01	(0.02)	96.9	9,300	(10,700)
Multiple-effect Evaporator	0.22	(0.43)	Scrubber	0.04	(0.08)	41.4	0.03	(0.05)	89.1	5,940	(6,550)
	0.22	(0.43)	Incineration	0.01	(0.02)	45.9	0.01	(0.02)	95.3	6,400	(7.050)
Lime Kiln	0.31	(0.62)	1) Process Controls	0.10	(0.2)	71.8	0.09	(0.18)	71.0	6,900	(7,600)
	0.31	(0.62)	2) Process Control & High Eff. Mud Washing	0.05	(0.1)	90.5	0.05	(0.1)	84.0	8,900	(9,800)
	0.31	(0.62)	3) Process Controls, High Eff. Mud Washing & Caustic Scrubbing	0.021	(0.04)	99.4	0.021	(0.04)	92.0	9,300	(10,250)
Brown Stock Washer System	0.15	(0.3)	Incineration	0.01	(0.02)	99.1	0.01	(0.02)	93.3	4,350	(4,800)
Black Liquor Oxidation System	0.05	(0.1)	Incineration	0.01	(0.02)	98.0	0.01	(0.02)	80.0	1,270	(1,400)
	0.05	(0.1)	Molecular Oxygen	0	(0)	98.0	0	(0)	100.0	1,540	(1,700)
Smelt Dissolving Tank	0.10	(0.2)	Fresh Water	0.013	(0.025)	--	0.01	(0.02)	87.5	2,800	(3,100)
Condensate Strippers	0.11	(0.22)	Incineration	0.01	(0.02)	20	0.01	(0.02)	90.9	3,130	(3,450)
	0.11	(0.22)	Scrubber	0.5	(1.0)	0	0.11	(0.22)	0	0	(0)

a particulate control device (Column 4) to those existing mills which are not presently achieving that level, as listed in Appendix A, and calculating the national average emission level that would result. Column 7 (Percent Emission Reduction Achieved Nationally) is the percent difference between Columns 2 and 6. The national emission reduction achieved by a specific control device (Column 8) was calculated by multiplying the difference between Columns 2 and 6 by the annual kraft pulp production rate (31,196,000 megagrams/year).

Table 9-1 shows that the greatest reduction of TRS emissions is achieved by controlling the recovery furnace system with the digester system, lime kiln, multiple-effect evaporator system, brown stock washer system, smelt dissolving tank, black liquor oxidation system and condensate stripping system following in decreasing impact.

Table 9-2 shows the impact of the various control systems mentioned in Section 6.2. For example, if System No. 1 (best available technology as defined for NSPS) was applied to each source, the TRS emissions from the kraft industry would be reduced by about 70,500 megagrams per year (77,700 tons per year) or 94.2 percent. System No. 5, if applied, would result in the least impact but would still reduce TRS emissions by about 59,000 megagrams per year (65,000 tons per year) or 78.8 percent. Control of four sources in a kraft mill account for a major portion of the impact achieved by each of the control systems. These four sources are the recovery furnace, digester system, multiple-effect evaporator system, and the lime kiln.

9.1.2 Annual Air Emission Increase

The only control techniques mentioned in Chapter 6 that would apparently result in increasing the emission rates of other pollutants is the incineration of the vent gases from the brown stock washer systems and the black liquor

TABLE 9-2

ENVIRONMENTAL IMPACT OF VARIOUS CONTROL SYSTEMS FOR EXISTING KRAFT PULP MILLS

Control System	Estimate Average TRS Emission With Control System g/Kg ADP	(#T ADP)	% Emission Reduction*	National Emission Reduction megagrams/year	(tons/year)
No. 1	0.14	(0.28)	94.2	70,500	(77,700)
No. 2	0.32	(0.64)	86.7	64,900	(71,500)
No. 3	0.44	(0.87)	81.9	61,300	(67,600)
No. 4	0.45	(0.89)	81.5	61,000	(67,200)
No. 5	0.51	(1.02)	78.8	59,000	(65,000)
No. 6	0.40	(0.79)	83.5	62,600	(69,000)

* Based on a current control level of 2.4 g/Kg ADP (4.8 lb/T ADP).

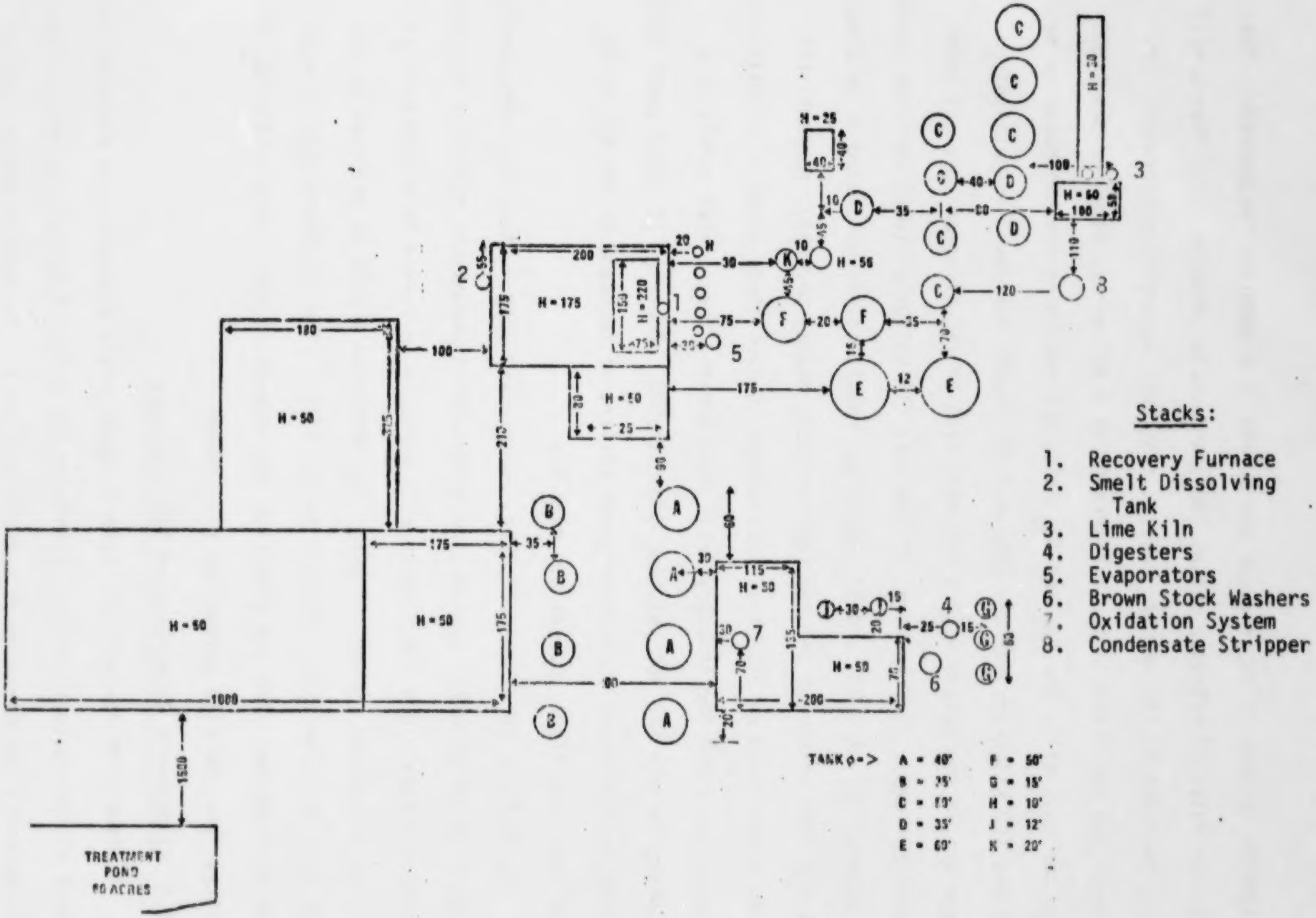
oxidation systems if these gases are burned in a separate incinerator. The emission rates of nitrogen oxides (NO_x) and sulfur dioxide (SO_2) from a mill would increase by the amounts emitted from this separate incinerator. If natural gas was fired in the incinerator at a 907 metric tons per day (1000 tons per day) mill, the NO_x and SO_2 emissions resulting are estimated to be 160 and 220 kilograms per day (350 and 480 pounds per day), respectively. These are in comparison with a TRS reduction of 180 kilograms per day (400 pounds per day). Furthermore, if fuel oil (1% sulfur content) was used instead of natural gas, the NO_x and SO_2 emissions resulting are estimated to be about 380 and 1040 kilograms per day (840 and 2280 pounds per day), respectively. Using a gas-fired or oil-fired incinerator to burn these gases is a realistic alternative since the industry feels that burning these gases safely in a recovery furnace has not yet been demonstrated. However, if these gases were burned in a recovery furnace or power boiler, no increase in the SO_2 or NO_x emissions from these sources are expected.

No increase in other pollutants is expected from burning the noncondensable gases from the digester systems, multiple-effect evaporator system or condensate stripper system since these gases will normally be burned in a lime kiln as part of the normal combustion air. SO_2 generated should be absorbed by the lime dust (calcium oxide) present in the kiln.[1] The scrubbers used on most lime kiln systems also are effective gas removal system. Very little SO_2 is emitted from the kiln system for this reason.

9.1.3 Atmospheric Dispersion of TRS Emissions

A dispersion analysis was made on model kraft pulp mills to evaluate the impact of the various control techniques and retrofit systems on ground-level TRS concentration downwind of a kraft pulp mill. The models chosen were of average design and layout as shown in Figure 9-1, and included the eight

FIGURE 9-1. Typical Plant Layout (100) ton per day kraft pulp mill)


H = 20
H = 25
H = 56
H = 175
H = 220
H = 50
TREATMENT POND 60 ACRES
TANK ϕ -> A = 40' B = 25' C = 18' D = 35' E = 60' F = 50' G = 15' H = 10' J = 12' K = 20'

Stacks:

1. Recovery Furnace
2. Smelt Dissolving Tank
3. Lime Kiln
4. Digesters
5. Evaporators
6. Brown Stock Washers
7. Oxidation System
8. Condensate Stripper

affected facilities being considered. Modeling was performed for mills of 500, 1000, and 1500 tons per day of air-dried pulp (ADP) produced, a range within which the majority of kraft pulp mill capacities fall.

Maximum ground-level concentrations of TRS were determined for the emission rates corresponding to each control technique and system. The concentrations decreased predictably with decreases in the emission rates. It was possible to adjust the meteorological conditions of the study to achieve the worst cases that would be expected to occur at and near a kraft pulp mill.

Ambient concentrations of TRS due to the alternative control techniques and systems were calculated using state-of-the-art modeling techniques. These calculations are assumed to be reliable within about a factor of two. The following assumptions were applied for the analytical approach:

1. There are no significant seasonal or hourly variations in emission rates for these mills.

2. The mills are located in flat or gently rolling terrain.

3. The meteorological regime is unfavorable to the dispersion of effluents. This assumption introduces an element of conservatism into the analysis. Calculations were performed assuming the presence of aerodynamic downwash effects on the emissions. Unfavorable design characteristics of the model mill such as: (1) a 220-foot structure adjacent to a 250-foot recovery furnace stack; (2) a 175-foot smelt dissolving tank stack next to a 175-foot building; and (3) a two-foot stack for the black liquor oxidation tank atop a 50-foot building will result in downwash in most situations. Maximum ground-level concentrations were estimated by assuming worst meteorological conditions. The correlation of those estimates with observed concentrations at any particular kraft pulp mill would depend upon many factors, including the accuracy of the emission data, the mill configuration, the distance from the mill at which

samples are obtained, the sampling period and the climatology of the mill location.

The estimated maximum ambient TRS concentration (10 second average) in a vicinity of a 907 megagrams (1000 tons) per day pulp mill resulting from the individual affected facilities with and without controls are listed in Table 9-3. The maximum concentrations occur at 300 meters from the source. Table 9-3 shows that the sources (excluding the condensate strippers) resulting in the greatest impact on ambient concentrations of TRS are, in decreasing order, the digester systems, multiple-effect evaporator systems, recovery furnace, and the lime kiln. An uncontrolled digester system can result in a maximum ambient TRS concentration of 20,000 μg/m^3 whereas an uncontrolled brown stock washer system results in a maximum ambient concentration of 370 μg/m^3. Table 9-3 also shows the percent reductions of applying each control technique on uncontrolled levels and the ambient levels at various distances under the controlled case.

Tables similar to Table 9-3 showing the impact of applying controls to the various TRS sources on ambient TRS concentrations in terms of one-hour and 24-hour averages and for 454 and 1350 megagrams (500 and 1500 tons) per day kraft pulp mills are included in Appendix C. For the stacks of each mill, all averaging period maximum concentrations are noted at extremely close-in distances (300 meters). This is due to considerable aerodynamic effect influencing the plume rise in each case. The distances given in the tables are distances from the stack in question. Concentrations closer to the stack than the 300 meters given may be even higher. These tables also give an estimate of the frequency of occurrence for the maximum ambient concentration due to each source. The TRS concentrations with low frequencies of occurrence are the

TABLE 9-3

IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES ON AMBIENT TRS CONCENTRATION FROM A 907 MEGAGRAMS/DAY KRAFT PULP MILL

		Maximum Ambient Concentration: $\mu g/m^3$ (10 second average)						Frequency - % of Concentrations Greater than 1/2 the Maximum	Percent Reduction[a]
		Uncontrolled	Distance from Source (km)						
Source	Control Techniques	Level @ 0.3 km	0.3	0.6	1.0	1.5	2.0		
Recovery Furnace	BLO (20 ppm)	8,030	320	210	120		50	28	96.0
	BLO (5 ppm)	8,030	80	50	30		13	28	99.0
Digester	Scrubber	20,000	15,290	5580	3550			3	23.5
	Incineration	20,000	0[b]					-	100.0
Multiple-Effect Evaporator	Scrubber	3,750	310	200	120			4	91.7
	Incineration	3,750	0[b]					-	100.0
Lime Kiln	1) Process Controls	800	200	70	55	45	40	1	75.0
	2) Process Controls + High Eff. Mud Washing	800	50	20	15	11	10	1	93.8
	3) Process Controls + High Eff. Mud Washing + Caustic Scrubbing	800	25	10	7	6	5	1	96.9
Brown Stock Washer System	Incineration	370	25		9	6		34	93.2
Black Liquor Oxidation System	Incineration	310	60	20	9	5	3	25	80.6
	Molecular Oxygen	310	0[c]					-	100.0
Smelt Dissolving Tank	Fresh Water	560	70		26	16		3	87.5
Condensate Stripping System	Scrubber	14,000	7,000		975	525		25	50.0
	Incineration	14,000	0[b]					-	100.0

[a] Reduction from uncontrolled average level

[b] Gases are assumed burned in the lime kiln. The levels from the lime kiln include unburned TRS portion of these gases.

[c] No vent gases.

10-second and 1-hour concentrations from the smelt dissolving tank, the digesters, and the multiple-effect evaporators, along with all three averaging period concentrations from the lime kiln. In each case, less than 5 percent of the averages during the year were above half the maximum value for the respective averaging periods. These maxima, then, appear to be caused by conditions of usually high wind speed which bring about aerodynamic downwash.

Table 9-4 shows the estimated maximum ambient TRS concentrations resulting from the various control systems. If System No. 1 (best available control technology) was applied to each source, the estimated maximum ambient TRS concentration would be 97 micrograms per cubic meter (10-second average). Control Systems No. 2 and No. 6 would reduce the average ambient TRS concentration around a kraft mill to about 308 $\mu g/m^3$ (10-second average). Application of Control Systems No. 3 and No. 5 would result in a maximum TRS ambient concentration of about 487 $\mu g/m^3$ (10-second average). These concentrations are mainly caused by emissions from three facilities: the recovery furnace, the smelt dissolving tank, and the brown stock washer system. Contribution to the maximum TRS ambient concentration due to emissions from the lime kiln and black liquor oxidation system are negligible in all cases. No values are reported for the digesters, multiple-effect evaporators and condensate strippers since it is assumed that the gases from these systems would be burned in the lime kiln.

Averaging times of 10 seconds, one hour, and twenty-four hours were selected for the TRS calculations, representing short and long-term exposures. The 10-second average would be considered a "whiff", and applicable to the study of odorous emissions. The one-hour average gives an indication of the level of exposure experienced through casual contact, while the 24-hour average shows the level of exposure of a person living near the mill.

TABLE 9-4. ESTIMATED IMPACT OF THE CONTROL SYSTEMS ON MAXIMUM AMBIENT TRS LEVELS AROUND AN EXISTING (907 MEGAGRAMS PER DAY) KRAFT PULP MILL

Control System	Averaging Time	Maximum Combined Concentration $\mu g/m^3$	CONTRIBUTION OF EACH SOURCE ($\mu g/m^3$)				
			RF	SDT	LK	BLO	BSW
1	10 sec	97	81	16	Neg.	--	--
	1 hr	30	25	5	Neg.	--	--
	24 hr	7	6	1	Neg.	--	--
2	10 sec	308	260	16	Neg.	Neg.	211
	1 hr	95	25	5	Neg.	Neg.	65
	24 hr	24	6	1	Neg.	Neg.	17
3	10 sec	487	260	16	Neg.	Neg.	211
	1 hr	150	80	5	Neg.	Neg.	65
	24 hr	38	20	1	Neg.	Neg.	17
4	10 sec	487	260	16	Neg.	Neg.	211
	1 hr	150	80	5	Neg.	Neg.	65
	24 hr	38	20	1	Neg.	Neg.	17
5	10 sec	487	260	16	Neg.	Neg.	211
	1 hr	150	80	5	Neg.	Neg.	65
	24 hr	38	20	1	Neg.	Neg.	17
6	10 sec	308	81	16	Neg.	Neg.	211
	1 hr	95	25	5	Neg.	Neg.	65
	24 hr	24	6	1	Neg.	Neg.	17

9.1.4 Changes in Solid and Liquid Wastes

Increased control of gaseous TRS compounds will not change the amount of solid waste generated by the kraft pulp industry since none of the control techniques result in collecting solids that can not be recycled to the process. Water effluent from a mill may increase, however, due to the various TRS controls. Controls requiring use of fresh water instead of contaminated condensate will result in an increase in the mill effluent of the amount of the condensate. This increase could be eliminated by using a condensate stripper and reusing the stripped water. A condensate stripper would also prevent the TRS dissolved in the condensate from being emitted from the treatment pond during aeration. Increasing the mud washing efficiency to control TRS emissions from the lime kiln can also increase the mill's water effluent. However, this additional effluent from the mud washer can probably be recycled back to the process.

9.1.5 Energy Consumption

The energy (fuel or electricity) required for each of the control techniques mentioned in Chapter 6 are listed in Table 9-5. The additional emissions resulting from a coal-fired power plant supplying the necessary power (electricity) for these control techniques are also listed in Table 9-5.

As indicated in Table 9-5, the additional particulate, SO_2 and NO_x emissions that will occur at a coal-fired power plant due to producing the electricity that will be required to control emissions is small compared to the TRS reduction that will be achieved at the kraft mill.

As indicated by Table 9-5, the only control techniques requiring additional fuel consumption at a kraft mill are incineration (in a separate incinerator) of the vent gases from the brown stock washer system and the black liquor oxidation system, and process controls used on the lime kiln. Incineration of the

TABLE 9-5

COMPARISON OF CONTROL TECHNIQUES ON ENERGY IMPACT FOR A 907 MEGAGRAMS PER DAY KRAFT PULP MILL

Source	Control Technique	Fuel Requirement 10^9 J/day	Fuel Requirement (10^6 Btu/day)	Electrical Requirement Kwh/day	Total Energy Requirement 10^9 J/day	Total Energy Requirement (10^6 Btu/day)	Emissions lb/day: Additional Emissions from Coal-Fired Power Plant Supplying The Electrical Energy[a]: Part.	Emissions lb/day: Additional Emissions from Coal-Fired Power Plant Supplying The Electrical Energy[a]: NO_x	Emissions lb/day: Additional Emissions from Coal-Fired Power Plant Supplying The Electrical Energy[a]: SO_2	Emissions lb/day: TRS Reduction from Control Technique
Recovery Furnace	BLO[b]	0	(0)	14,400	52	(49)	5.7 (12.6)	40 (88)	68 (150)	650 (1440)
	Non-contact evaporator	1150	(1090)	0	1150	(1090)	0 (0)	0 (0)	0 (0)	650 (1440)
Digester System	Scrubbing	0	(0)	2,880	11	(10)	1.1 (2.5)	8 (18)	14 (30)	180 (400)
	Incineration	0	(0)	2,880	11	(10)	1.1 (2.5)	8 (18)	14 (30)	680 (1500)
Multiple-effect Evaporator System	Scrubbing			INCLUDED IN DIGESTER SECTION						420 (920)
	Incineration									450 (1000)
Lime Kiln	Process Controls	150	(142)	1,075[c]	154	(146)	0.5 (1.0)	3 (7)	5 (12)	270 (600)
	Process Controls & High Eff. Mud Washing	150	(142)	1,075[c]	154	(146)	0.5 (1.0)	3 (7)	5 (12)	340 (750)
	Process Controls, High Eff. Mud Washing & Caustic Scrubbing	150	(142)	1,075[c]	154	(146)	0.5 (1.0)	3 (7)	5 (12)	350 (775)
Brown Stock Washer System	Incineration	2340	(2220)	5,376	2360	(2240)	2.1 (4.7)	15 (33)	25 (56)	140 (300)
Black Liquor Oxidation System	Incineration			INCLUDED IN WASHER SECTION						45 (100)
	Oxygen	0	(0)	20,000	80	(68)	8.0 (17.5)	55 (122)	95 (210)	45 (100)
Smelt Dissolving[d] Tank	Fresh Water	0	(0)	2,400	8	(8)	1.0 (2.1)	7 (15)	11 (25)	80 (175)
Condensate Stripper System	Incineration	0	(0)	840	3	(3)	0.3 (0.7)	2 (5)	4 (8)	910 (2000)

[a] Data are based on the new source performance standards for coal-fired power plants (Part. - 0.1 lb/10^6 Btu; NO_x - 0.7 lb/10^6 Btu; SO_2 - 1.2 lb/10^6 Btu).

[b] Requirements are for two-stage oxidation.

[c] Electrical requirement is for operating a condensate stripper to TRS from scrubbing water, if contaiminated condensate is used.

[d] Requirements are for a scrubbing system, if a scrubber is not already used to control particulate emissions

noncondensable gases (digester, multiple-effect evaporator, and condensate stripper) would not require additional fuel if they are burned in the lime kiln as part of the primary air feed.

Incineration of the vent gases from the brown stock washers and black liquor oxidation system would require an additional fuel consumption of 2340 X 10^9 joules/day (2,220 million Btu/day).

It is estimated that an additional 150 X 10^9 joules/day (142 million Btu/day) of fuel (without consideration of extra heat losses) will be required when process controls (higher cold end temperatures and higher oxygen levels) are used to control TRS compounds from a lime kiln. This is approximately five percent of the normal fuel consumption of a lime kiln.

The additional electrical energy needed for each of these control techniques is estimated to be between zero and 15,000 kilowatt-hours per day. Control System 1 would require about 23,500 kilowatt-hours per day of additional electrical energy. Control Systems 2 through 6 would require about 18,125 kilowatt-hours per day of additional electrical energy. An additional 350 kilowatt-hour per day would be required for each system if a condensate stripper and a scrubber for the smelt dissolving tank are needed.

Each control system would result in an additional fuel requirement of 150 X 10^9 joules/day (for lime kiln controls) except for Control System No. 1, which would result in an additional fuel requirement of 2482 X 10^9 joules/day (incineration of BLO and washer gases). A pulp and paper mill requires an electrical requirement in the order of 700 to 1400 kilowatt-hours per ton of product.[2] Therefore, these control systems will result in an increase of between one to three percent of the total mill electrical usage.

REFERENCES FOR CHAPTER 9

1. Incineration of Malodorous Gases in Kraft Pulp Mills, Burgess, T. L., Cater, D. N., and McEachern, D. E. Pulp and Paper Magazine of Canada. Volume 75, Number 5. May 1974.

2. Energy and Air Emissions in the Pulp and Paper Industry. James E. Roberson, J. E. Sirrine Company. Greenville, South Carolina.

10. EMISSION GUIDELINES FOR EXISTING KRAFT PULP MILLS

Various alternative control systems can be applied to existing kraft pulp mills as described in Chapter 6. This chapter will select a system which is judged to be the best for existing plants when costs are taken into account, and will specify emission limitations that reflect the application of such a system. Time requirements to incorporate control techniques for each affected facility are discussed in Section 6.3. Section 10.3 will briefly discuss why the other control systems were not selected as best retrofit technology.

10.1 GENERAL RATIONALE

The best retrofit control technologies for the reduction of TRS emissions, taking into account the cost of this control, correspond to alternative control system No. 4, as indicated in Table 6-2. The recommended control technologies for brown stock washers, lime kilns, and black liquor oxidation systems are less restrictive than those that have been proposed by EPA for new kraft pulp mills. The recommended control technologies for the recovery furnace, digesters, multiple effect evaporators, smelt dissolving tank, and condensate stripper are the same for both new and existing sources. The following factors were considered in determining best retrofit control technology:

1. The degree of emission reduction achievable through the application of various demonstrated control technologies.

2. The technical feasibility of applying the various demonstrated technologies to existing sources. In particular, more than one basic design of existing recovery furnace was evaluated.

3. The impact of the various control technologies on national energy consumption, water pollution, solid waste disposal, and ambient air concentrations of TRS.

4. The cost of adopting the emission guidelines. Control costs were estimated for each alternative control system for each retrofit model, taking into account the level of existing controls.

Identification of the best demonstrated control technology for new mills was accomplished during the development of NSPS for the kraft pulp industry. A question that must be answered by this study is whether or not it is technically and economically feasible to apply this technology to existing sources. Where this is not feasible, best retrofit technology considering cost is identified.

Evaluation of the technical problems and costs associated with a retrofit project is complicated by the lack of actual data for some sources. For example, only recently has an existing brown stock washer system and black liquor oxidation system been retrofitted for control of TRS. Also, no new black liquor oxidation units have been installed with control systems. Retrofit information on control systems was available for the other process facilities in existing mills. Retrofit models were developed (see Section 6.2) to evaluate the environmental and cost impacts of installing TRS controls on existing recovery furnaces, digesters, multiple-effect evaporators, lime kilns, brown stock washers, black liquor oxidation systems, smelt dissolving tanks, and condensate strippers. The retrofit model approach presents the impacts on an entire kraft pulp mill of applying control technologies to individual sources of TRS. The major technical problem, aside from space limitations, foreseen for the average mill is the ability of existing furnaces to maintain good combustion for TRS control while burning the vent gases from the pulp washer and the black liquor oxidation system.

Table 10-1 indicates the impact on annual TRS emissions from the kraft industry if best retrofit control technology, (i.e. alternative control system No. 4) was used. Adoption of best retrofit control technology would result in emission reductions ranging from 40 percent at typically controlled mills to 95 percent at uncontrolled mills. Total emissions from the industry would be reduced by about 81 percent, resulting in a national TRS reduction of about 60,900 megagrams per year (67,150 tons per year).

Adoption of best retrofit control technology will result in a maximum reduction of 95 percent in ambient air concentrations at uncontrolled mills. Emission reductions, and likewise control costs, will be less for mills which have already installed some control systems.

10.2 SELECTION OF BEST RETROFIT TECHNOLOGY AND EMISSION GUIDELINE

10.2.1 Recovery Furnace System

Emission Guideline - "Old Design" furnaces (i.e., furnaces without membrane wall or welded wall construction, or emission-control designed air systems): 20 ppm of TRS as H_2S (0.3 g/Kg ADP) on a dry gas basis and as a 12-hour average, corrected to 8 volume percent oxygen.

- "New Design" furnaces (i.e., furnaces with both membrane wall or welded wall construction and emission-control designed air systems): 5 ppm of TRS as H_2S (0.075 g/Kg ADP) on a dry gas basis and as a 12-hour average, corrected to 8 volume percent oxygen. (A "New Design" furnace will have stated in its contract a TRS performance guarantee or that it was designed with air pollution control as an objective.)

- Cross recovery furnaces (i.e., furnaces with green liquor sulfidities in excess of 28 percent and liquor mixtures of more than 7 percent NSSC on an air dry ton basis): 25 ppm of TRS as H_2S (0.6 g/Kg ADP) on a dry gas basis and as a 12-hour average, corrected to 8 volume percent oxygen.

Table 10-1. BEST RETROFIT CONTROL TECHNOLOGY AND IMPACT FOR INDIVIDUAL SOURCES IN THE EXISTING KRAFT PULP INDUSTRY

Source	Best Demonstrated control technique	TRS level achievable	Resultant TRS reduction at an average kraft mill (% of total mill emissions)	Resultant national TRS reduction (tons/year)
Recovery furnace	Process controls + BLO	20 ppm*(Old Design) 5 ppm*(New Design) 25 ppm*(Cross Recovery)	44.2	36,500
Digester system	Incineration	5 ppm	13.0	10,700
Multiple-effect evaporator system	Incineration	5 ppm	8.6	7,050
Lime kiln	Process controls (inc. high eff. mud washing)	20 ppm**	11.9	9,800
Brown stock washer system	No control	-	0	0
Black liquor oxidation system	No control	-	0	0
Smelt dissolving tank	Fresh water	0.0084 g/kg BLS	3.7	3,100
Condensate stripping system	Incineration	5 ppm	neg.	neg.
		Total % reduction =	81.4	67,150

*One percent of all twelve-hour TRS averages above the specified level are not considered to be excess emissions.
**Two percent of all twelve-hour TRS averages above 20 ppm are not considered to be excess emissions.

Discussion - The emission guidelines represent the levels that can be achieved by using a two-stage black liquor oxidation system together with good furnace operation. The two specified levels of TRS emissions for straight kraft recovery furnaces reflect the dependence of TRS emissions on the design of the furnace, which in turn depends on the age of the recovery furnace. While the design of the furnace affects the TRS level that can be achieved, the reduction of TRS emissions from the direct contact evaporator necessary to reduce emissions to the level of the guidelines requires the use of high efficiency black liquor oxidation systems regardless of the design of the furnace. Most recovery furnaces constructed since 1965 are generally considered capable of achieving 5 ppm TRS because the furnace design is basically similar to furnaces presently being installed which can achieve 5 ppm TRS.[1] Approximately 40 percent of the existing recovery furnaces were constructed after 1965. Recovery furnaces which were constructed before 1965 generally do not have the appropriate design (i.e., membrane or welded wall construction and flexibility of air distribution) or instrumentation necessary for achieving 5 ppm. As confirmed by the two furnace manufacturers,[2,3] however, these older furnaces are generally capable of limiting TRS emissions to 20 ppm if the furnace is properly operated, uses high efficiency black liquor oxidation, and is not operated at an excessive production rate.

As mentioned in Chapter 6, cross recovery liquors are somewhat different than straight kraft liquors. Consequently, TRS emissions from a cross recovery furnace are not controllable to the same degree as are those from straight kraft recovery furnaces. The reasons for this include higher sulfur-to-soda ratios and lower BTU value of the liquor fired. Furthermore, the technique of using excess combustion air (high oxygen levels) to reduce TRS emissions is of limited utility because it reportedly results in a sticky dust which will foul the precipitator and render furnace operation difficult or impossible. Tests performed on a non-contact type cross-recovery furnace indicate that TRS emission levels of 25 ppm (12-hour average) can be achieved from well controlled cross recovery furnaces.[4]

Appendix B presents TRS emission data for straight kraft recovery furnaces and a cross recovery furnace.

Retrofit annualized costs for installing a second stage of black liquor oxidation are about $240,000 for a 907 megagrams/day (1,000 tons ADP/day) mill. Retrofit costs would be double if a mill does not presently have a single stage of oxidation. Annualized costs, including capital charges, are estimated to be about $0.75 per ton ADP, or about 0.25 percent of the pulp price to install a second stage of black liquor oxidation. These costs are not considered excessive.

It appears that approximately 18 recovery furnaces may not be able to achieve 20 ppm TRS because the furnace either does not have sufficient control for proper combustion or is operated at an excessive production rate and cannot supply sufficient oxygen to achieve good combustion. Studies have demonstrated that minimum TRS emissions are not achieved unless residual oxygen content of the flue gas is in the range of 2.5 to 4.5 percent. (Low oxygen levels due to overloading of the furnace can exist regardless of the age of the furnace.) If these furnaces are required to achieve the emission guideline, a new furnace would have to be installed (at an annualized cost of about $2.3 million for a 500 tons per day furnace) to compensate for the cutback on production of an existing furnace. Many of the recovery furnaces that would have to be replaced are at least 20 years old [this age is near the normal life (25 years) of a furnace, considering the compliance schedule under Section 111(d)] and may be near replacement.

An alternative to replacing an old furnace would be to install a scrubber system, as mentioned in Section 6.11, which is capable of achieving less than 20 ppm TRS. A scrubber system has been installed at one mill.[5] Installation and operation of such a system is expected to be a much less expensive alternative than replacement of the furnace.

The emission guidelines for recovery furnaces are comparable to the emission levels which existing furnaces in Oregon and Washington are required to meet as of July, 1975 (17.5 ppm).[6] The 17.5 ppm level represents the level that can be achieved by most existing recovery furnaces, and the 1983 Oregon and Washington level of 5 ppm represents the level achievable with the newer design furnaces and allows time for the replacement of older furnaces (non-membrane wall construction).

The estimated impact of adoption of the emission guideline on annual TRS emissions from recovery furnaces is 33,470 megagrams per year, an 85 percent reduction. The predicted maximum ambient air TRS concentration due to emissions from an uncontrolled recovery furnace would decrease by 96 to 99 percent with the recommended control technology.

10.2.2 Digester System

Emission Guideline - 5 parts per million of TRS as H_2S on a dry gas basis and as a 12-hour average.

Discussion - This TRS level is the same as that included in the new source performance standards for new digester systems. The 5 ppm level is achievable by incineration of the noncondensable gases. Existing mills in Oregon, Washington, and several other states are required to incinerate the noncondensable gases from digester systems as of July, 1975.[7] It is estimated that adoption of this control technology will result in a reduction of 99 percent in the uncontrolled TRS emitted from a digester system.

The TRS level achievable by incineration of noncondensable gases from digester systems has been well-demonstrated as reported in Section 6.1.2. The gases from the digester system can be handled in the lime kiln as part of the combustion air without requiring extensive modification to the digester system or lime kiln. Incineration of the gases in lime kilns or in power boilers is presently being accomplished by at least 60 mills. Nearly all of these incineration systems were retrofitted to the existing mills.

Incineration is so far the only control option capable of providing high efficiency TRS reduction. A thousand-fold increase in emissions to approximately 7000 ppm would result from control by white liquor scrubbers (see Chapter 6). These scrubbers are effective in controlling H_2S and methyl mercaptan which comprise only approximately 20 percent of the TRS emissions from digester systems.

If the emission guidelines were increased moderately, incineration costs would not vary greatly. The cost of collecting and burning the gases in the lime kiln is essentially fixed regardless of the selected emission level. Most existing kraft pulp mills incinerate these gases in the lime kiln and normal kiln operation will oxidize the TRS compounds to less than 5 ppm.

Retrofit annualized costs are estimated to range from about $65,000 to about $210,000 for a 454 megagram mill, or about $0.40 to $1.25/T ADP. The low value represents costs for piping only, while the high value represents costs for piping, blow heat recovery system, and a separate incinerator. These costs are not considered excessive.

The estimated impact of adoption of best retrofit control technology on annual TRS emissions from digester systems is significant, 11,800 megagrams per year or a 97 percent reduction from uncontrolled levels.

10.2.3 Multiple-Effect Evaporator System

Emission Guideline - 5 parts per million of TRS as H_2S on a dry gas basis and as a 12-hour average.

Discussion - This TRS level is also the same as that in the new source performance standards for new multiple-effect evaporator systems. It is estimated that achievement of this level will require a reduction of 98 percent of the TRS emitted from an uncontrolled multiple-effect evaporator system. Incineration is capable of achieving this level. Existing mills in Oregon, Washington, and several other States are required to incinerate these gases as of July, 1975.[8]

The TRS level achievable by incineration has been well-demonstrated as reported in the Standards Support and Environmental Impact Statement document for new kraft pulp mills. The non-condensable gases from the multiple-effect evaporators can easily be handled in the lime kiln as part of the combustion air without requiring extensive modifications to be made to the multiple-effect evaporator system or the lime kiln. Incineration of these gases in lime kilns or in power boilers is presently being accomplished by at least 59 mills. The majority of these incineration systems were retrofitted to existing multiple-effect evaporator systems.

Incineration is so far the only control option capable of providing high efficiency TRS reduction. A sixty-fold increase in TRS emissions to approximately 300 ppm (see Section 6.1.3) would be required to allow the use of white liquor scrubbers. These scrubbers have only about a 90 percent TRS collection efficiency when used on the noncondensable gases from a multiple-effect evaporator system.

If the emission guidelines were increased moderately, incineration costs would not vary greatly. The control costs are mainly for collecting and transferring the gases to the control device whether incineration or scrubbing is practiced.

Most existing kraft pulp mills incinerate the gases in the lime kiln along with the digester gases, and normal lime kiln operations oxidize the gases to less than 5 ppm TRS.

Retrofit costs for incineration of the noncondensable gases from the multiple-effect evaporators are included in the retrofit costs reported for the digester system (Section 10.2.2).

Estimated impact of adoption of best retrofit technology on annual TRS emissions from multiple-effect evaporator systems is significant, 6,120 megagrams (6,750 tons) per year or a 96 percent reduction.

10.2.4 Lime Kiln

Emission Guideline - 20 ppm of TRS as H_2S on a dry gas basis and as a 12-hour average, corrected to 10 volume percent oxygen.

Discussion - The specified level reflects the dependence of TRS emissions on the operation of the kiln. This requires maintaining the proper oxygen level and cold-end temperature, and using water that does not contain dissolved sulfides in the particulate control scrubber. Existing mills will probably need to improve their lime mud washing efficiency (additional filtration and clarifier capacity) to reduce the sulfide level of mud fed to the kiln. Additional fan capacity may be necessary to obtain the required oxygen levels in existing kilns and thereby provide appropriate control over the combustion. There are no apparent reasons why these changes cannot be made to existing kilns. Furthermore, installation of a condensate stripper may be required to remove sulfides from the condensate if it is used in the particulate control scrubber. Appendix B presents TRS emission data, which were obtained during the NSPS program, for several lime kilns that achieve this level.

Retrofit annualized costs for additional fan capacity (to achieve higher oxygen levels) and instrumentation are about $55,000 for a 458 megagrams/day (500 ton ADP/day) mill. Retrofit annualized costs for additional mud washing capacity are about $90,000. An additional $90,000 in retrofit annualized costs would be incurred if a condensate stripper is needed to remove the sulfides from the scrubbing water. These annualized costs, including capital charges, are estimated to be about $0.90 per ton ADP if a condensate stripper is not needed and about $1.50 per ton ADP if one is needed. These costs are not considered excessive.

The impact of adoption of best demonstrated retrofit control technology on TRS emissions from kraft lime kilns is significant, an 84 percent reduction (9,800 tons/year) from existing levels. Maximum ambient TRS concentration due to an uncontrolled lime kiln would be reduced by 83 percent.

Lower TRS levels than the emission guideline are achievable as stated in Section 6.1.4 and as reflected in the proposed standard for new lime kilns (8 ppm TRS). The lower TRS level is achievable with the addition of caustic scrubbing.

Many existing lime kilns are operating in excess of design capacity, and some of these kilns, even with improved mud washing efficiency, may not be able to achieve TRS levels significantly lower than 40 ppm because of the inability to supply sufficient oxygen for good combustion. It appears that between 20 and 33 lime kilns (corresponding to about 20 percent of the existing kilns) would have to be replaced or added in order to achieve 20 ppm TRS by applying the best retrofit control technology discussed above (see Chapter 8). Capital costs for a new lime kiln are $3 million, and annualized costs are $510,000.

The lower TRS emission level of 8 ppm is not recommended as an emission guideline so that the number of kiln replacements is minimized. The higher level also allows som of those mills which cannot achieve 20 ppm from the lime kiln by applying process controls and improved mud washing to apply caustic scrubbing to achieve the guideline rather than replacing or adding a new lime kiln. The results of trials conducted at one pulp mill showed that levels of 40 to 50 ppm TRS could be reduced to a level less than 20 ppm by using caustic addition.[9] Nevertheless, the lower TRS level is technically achievable at existing mills and can be imposed if the location of the mill or lime kiln warrants additional controls.

10.2.5 Brown Stock Washer System

Emission Guideline - No emission guideline is recommended for existing brown stock washer systems.

Discussion - No TRS control is recommended due to the high costs associated with hooding and collecting the gases and the possible effect the gases may have on existing recovery furnace operation.

Incineration of the vent gases is the emission control technique that could be used to reduce TRS emissions from brown stock washer systems. Burning these gases in an existing recovery furnace is considered by furnace manufacturers to be technologically feasible.[10] This control technique, however, has not yet been demonstrated on an existing furnace, and the TRS level that can be achieved from an existing furnace under these conditions has not been demonstrated. The control costs for incineration, therefore, have been based on the use of a separate incinerator. Incineration of the gases would require that the washer be hooded, possibly with enclosed hoods, and ductwork would be necessary to transfer the gases to the incinerator. (These gases would have to be ducted over 1500 feet at some mills if the recovery furnace was used.) Incineration of gases in a separate incinerator would require retrofit annualized costs of about $900,000 for a 454 megagram mill or about $5.50/T ADP. These costs are much more severe than retrofit costs for the other TRS sources and are considered to be excessive in comparison with control of the other sources of TRS and with the amount of TRS reduction achieved (about 1 percent of total mill TRS emissions).

10.2.6 Black Liquor Oxidation System

Emission Guideline - No emission guideline is recommended for existing black liquor oxidation systems.

Discussion - No TRS control is recommended due to the expected cost impact on the industry if existing sources were required to meet TRS levels achievable for new systems. There is no less stringent control method possible (except for the uncontrolled level) than that considered demonstrated for new sources.

Achievable control technology involves incineration of the vent gases or the use of molecular oxygen instead of air to eliminate the vent gases. The cost of controlling the low concentration/high volume gases from black liquor oxidation systems is considered more severe and excessive in comparison with controlling the largest sources of TRS at kraft mills (see Section 10.3). The control costs for incineration have been based on the use of a separate incinerator, since the effect of these oxygen-deficient gases on furnace combustion and thus TRS emissions from existing furnaces has not been determined. Retrofit annualized costs are estimated to be $230,000 for a 500 TPD kraft mill, or $1.50/T ADP. These costs are considered excessive in view of the amount of TRS reduction that would be achieved by incineration (about 0.4 percent of total mill TRS emissions).

10.2.7 Condensate Stripping System

Emission Guideline - 5 parts per million of TRS as H_2S on a dry gas basis and as a 12-hour average.

Discussion - This emission guideline is the same as that included in the new source performance standards for new condensate stripping systems. Only five existing mills have condensate strippers, and only one is not presently incinerating the off-gases. Incineration of the off-gases is necessary to achieve this TRS level.

Retrofit annualized costs based on combining the stripper off-gases with the noncondensable gas from the digesters and evaporators are estimated to be about $6,500 for a 500-ton-per-day mill or about $0.05/T ADP. The cost impact on the industry due to control of this facility is expected to be negligible.

Use of a white liquor scrubber, the only other control technique used, would permit TRS emissions which are 100-fold higher than with incineration. These TRS levels from scrubbers could be highly odorous.

10.2.8 Smelt Dissolving Tank

Emission Guideline - 0.0084 g/kg BLS of TRS as H_2S (approximately 8 ppm), on a 12-hour average.

Discussion - This emission guideline is also the same as that included in the new source performance standards for new smelt dissolving tanks. Achievement of this level would require the use of fresh water, or possibly weak wash liquor, in the particulate control device (scrubber) to ensure compliance.

The control costs for achieving this level are not considered excessive. Adoption of this level is expected to result in an emission reduction of about 2720 megagrams (3000 tons) per year of TRS.

10.2.9 Excess Emissions

Excess emissions are defined as emissions exceeding the numerical emission limit included in an emission guideline. Continuous emission monitoring, however, will identify all periods of excess emissions, including those which are not the result of improper operation and maintenance and therefore are not to be considered as violations. Excess emissions due to start-ups, shutdowns, and malfunctions, for example, are unavoidable or beyond the control of an owner or operator and cannot be attributed to improper operation and maintenance. Similarly, excess emissions as a result of some inherent variability or fluctuation within a process which influences emissions cannot be attributed to improper operation and maintenance, unless these fluctuations could be controlled by more carefully attending to those process operating parameters during routine operation which have little effect on operation of the process, but which may have a significant effect on emissions.

To quantify the potential for excess emissions due to inherent variability in a process, continuous emission monitoring data are used whenever possible to calculate an excess emission allowance. For kraft pulp mills, this allowance is defined as follows. If a calendar quarter is divided into discrete contiguous twelve-hour time periods, the excess emission allowance is expressed as the percentage of these time periods excess emissions may occur as the result of unavoidable variability within the kraft pulping process. Thus, the excess emissions allowance represents the potential for excess emissions under conditions of proper operation and maintenance, in the absence of start-ups, shutdowns, and malfunctions, and is used as a guideline or screening mechanism for interpreting the data generated by the excess emission reporting requirements. The definitions of excess emissions for recovery furnaces and lime kilns are discussed below.

Recovery Furnace Systems - A pulp manufacturer submitted six months of TRS emission data from one of their new design recovery furnaces and requested that EPA consider the data in defining excess TRS emissions from recovery furnace facilities. The furnace was tested by EPA in developing the data upon which the new source performance standard is based. The submitted data, recorded by a continuous monitor, show that over the 6-month period, the percent of time that the TRS concentration exceeded 5 ppm during each month ranged from 0 to 4.9 percent and averaged about 1 percent in normal operation (including load changes). EPA has investigated the furnace operation and the monitoring system at this mill and believes that the data are a true indication of normal, well controlled operation for this furnace.

For cross recovery furnaces similar excess emissions can be predicted. For old design recovery furnaces, no such continuous monitoring data are available. However, considering that the excess emissions allowance must represent the potential for excess emissions due to inherent reliability in the process itself and that the stringency of the standard for new design furnaces is at least comparable to that for old design furnaces, it appears reasonable to use the same excess emissions allowance. Therefore, based on that information, an allowance of 1 percent of the 12-hour averages has been given for excess TRS emissions above the guideline.

Lime Kiln - Test data on a 4-hour basis (see Appendix B) were supplied by a mill (Lime Kiln P) that had retrofitted the lime kiln system with additional fan capacity and mud washing capacity. These data give an indication of the variations in the emission concentrations over a large number of four-hour periods. The data show that for the period when the mill was maintaining good process controls (high cold end temperatures, high oxygen levels, and high mud solids contents) on the kiln, the four-hour average TRS concentrations exceeded 20 ppm for approximately 11 percent of the time.[11] However, during this same period the mud filter (belt filter) was inoperative for 10 percent of the time. However, process and emission monitoring data obtained on Lime Kiln E (see Appendix B) show excess TRS emissions of 2 percent on a 4-hour average basis over the 8 ppm level with down time on the mud filter (vacuum drum) of only 1 percent.

From the comparison of those two sets of data, it was felt that had the mud filter on Lime Kiln P been operating properly, as had that of Lime Kiln E, there would have been excess emissions only 2 percent of the time, instead of 11 percent, on a 4-hour average basis. With a 12-hour averaging period, Lime Kiln E should have no excess emissions during normal operation.[12] However, the data do not support this conclusion for Lime Kiln P.

Therefore, it is felt that with a reliable mud filtering system and maintaining good process controls on the kiln, the 12-hour average TRS concentrations will exceed 20 ppm for no more than 2 percent of the time. Hence, an allowance of a maximum 2 percent of the 12-hour averages is advised for excess TRS emissions above the guideline.

10.3 SUMMARY OF THE RATIONALE FOR SELECTING THE BEST RETROFIT CONTROL SYSTEM

The proposed TRS emission limits for new kraft pulp mills are technologically achievable at existing kraft pulp mills when the best control techniques discussed above are applied to each of the eight component process operations. However, the costs of applying the best control techniques are considered excessive for some existing mills, in part because some techniques involve replacement of recovery furnaces or lime kilns. Further, alternative control techniques which are effective but less costly are available for some process operations. Therefore, the cost of applying the various control techniques had a considerable influence on the selection of the recommended best retrofit control technology (alternative control system No. 4 for an entire kraft mill).

Control of the brown stock washer system and black liquor oxidation system (alternative control system No. 1) are not recommended because incineration of these vent gases in a separate incinerator would result in excessive operating costs and fuel requirements in comparison to the TRS reduction achieved by the control technique. Incineration of these gases in an existing recovery furnace is not presently considered to be demonstrated retrofit technology. No existing recovery furnace not designed to handle these gases has demonstrated the ability to burn these gases and still maintain proper combustion for controlling TRS emissions from the furnace itself.

The emission guideline recommended for existing recovery furnaces is 20 ppm for "old design" furnaces, 5 ppm for "new design" furnaces, and 25 ppm for cross recovery furnaces. The older furnaces are not capable of achieving 5 ppm and a large number of existing furnaces would most likely have to be replaced if such a level was required. The control technique required for each type of furnace to meet the recommended levels is two-stage black liquor oxidation and process controls.

Incineration of the noncondensable gases from the digesters, multiple-effect evaporators, or condensate strippers in the lime kiln has been demonstrated at many existing mills. Therefore, since the control costs are not excessive, the emission guideline recommended is the same as the new source performance standard (5 ppm TRS) for new kraft pulp mills.

An emission guideline of 20 ppm TRS is recommended for existing lime kilns. Emission data obtained during the NSPS program show that 20 ppm can be achieved with proper kiln operation and sufficient mud washing efficiency. Larger fans and additional mud washing capacity will be necessary for most existing kilns. Lower TRS levels are achievable, but several additional lime kilns would have to be replaced or added in order to achieve a level of 8 ppm TRS.

The emission guideline recommended for smelt dissolving tanks will probably prevent the use of contaminated condensate in the tank and the particulate control device, if one is used. If a scrubber is not used already for controlling particulates, one may have to be installed to reduce TRS emissions from an existing smelt dissolving tank to the recommended guideline.

The best retrofit technologies (alternative control system No. 4) will produce a large reduction in national TRS emissions (67,150 tons/year) and in ambient TRS concentrations around existing mills.

10.4 SELECTION OF THE FORMAT OF THE EMISSION GUIDELINES

Standards for kraft pulp mills could be expressed in terms of either mass emissions per unit of production or a concentration of pollutant in the effluent gases. The most common format now used by the industry and state control agencies is pounds of pollutant per ton of air-dried unbleached pulp produced (lb/T ADP). This format offers the advantage of preventing circumvention of the standards by the addition of dilution air or the use of excessive quantities of air in process operations. The principal disadvantage is that a control agency cannot readily or accurately measure the pulp production over the short term. Due to storage capacity of the mill, the recovery furnace, smelt dissolving tank, lime kiln, condensate strippers, black liquor oxidation tanks, and multiple-effect evaporators can be operating on accumulated inventories when the digesters are off-stream (no pulp production). Similarly, the above facilities can be operating below capacity even though the pulp production may be at design rates.

Concentration units are used as the format for the emission guidelines for the digesters, the multiple-effect evaporators, the recovery furnace, the lime kiln, and the condensate stripping system. The reasons for the selection of this format are outlined below:

a. Concentration units can be corrected for excess oxygen in the lime kiln and recovery furnace exhaust streams, precluding circumvention of the standards by dilution.

b. The reference test method for TRS produces data in concentration units. No conversion factors are therefore required in determining compliance for the affected facilities.

c. Average concentrations rather than instantaneous concentrations are proposed to allow for fluctuations in emissions which occur even during periods of normal operation.

d. Commercially available continuous monitors that may be used to measure emissions from these facilities indicate concentration directly. A direct indication of performance of the control systems would be available, and therefore the operator would be aware of excess emissions that require corrective action.

The emission guideline for smelt dissolving tanks is expressed in grams per kilogram BLS (g/kg BLS). Dilution cannot be prevented by correcting for excess oxygen because the exhaust stream discharged from the smelt dissolving tank is mostly ambient air.

10.5 RECOMMENDED MONITORING REQUIREMENTS

Monitoring requirements are necessary to ensure proper operation and maintenance of the affected facility and its associated control system. The volume concentration of TRS emissions can be monitored by use of measurement systems (see Chapter 7). Since there are no process or control device parameters that are appropriate indicators of concentration of TRS emissions from recovery furnace systems and lime kilns, it is recommended that TRS continuous monitors be required for recovery furnaces and lime kilns; however, it is also recommended that those requirements not become effective until promulgation of performance specifications for TRS monitors.

TRS concentrations in the effluent gases from an incinerator that controls TRS emissions (from the digesters, multiple-effect evaporators, and/or condensate strippers) can be measured by a continuous monitoring system. An effective alternative method of monitoring TRS emissions from an incinerator is continuous measuring and recording of the fire box temperature of 540°C (1000°F) and operation at a residence time of at least one-half second in the fire box. Incinerators are designed for a particular residence time that will not be reduced if the incinerator is not operated above its design capacity. The fire box temperature can be readily measured and recorded. If noncondensable gases from facilities that are covered by the guidelines are incinerated in the recovery furnace or the lime kiln, the TRS monitoring system on the furnace or the lime kiln will serve to monitor the sources that are being incinerated.

Since the guideline for smelt dissolving tanks is expressed in a format of pollutant mass per unit of feed to the furnace, the gas flow rate and the feed rate to the furnace would have to be measured simultaneously to reduce the TRS concentrations measured by the monitor to units of the recommended guideline. The inaccuracies involved in continuously measuring emissions from the smelt dissolving tank are felt to be sufficiently large that no direct monitoring of TRS emissions from the smelt dissolving tank is recommended.

References for Chapter 10

1. Letter from J. W. Kesner of Babcock and Wilcox Company to James Eddinger of EPA, dated May 27, 1975.
2. Presentation given by Julius Gommi of Combustion Engineering at the NAPCTAC meeting in Raleigh, North Carolina, on March 3, 1977.
3. Op. cit., Reference 1.
4. A Report on the Study of TRS Emissions from a NSSC - Kraft Recovery Boiler, Container Corporation of America, March 9, 1977.
5. Considerations in the Design for TRS and Particulate Recovery from Effluents of Kraft Recovery Furnaces, Teller, A. J., and Amberg, h. r., Preprint, TAPPI Environmental Conference, May, 1975.
6. Analysis of Final State Implementation Plans Rules and Regulations, prepared by the MITRE Corporation for the U.S. Environmental Protection Agency, Contract No. 68-02-0248, July, 1972.
7. Op. cit., Reference 6.
8. Op. cit., Reference 6.
9. Telephone conversation between Larry Weeks of Hoerner-Waldorf Corporation and James Eddinger of EPA on September 6, 1977.
10. Op. cit., Reference 1.
11. Letter from Richard C. Wigger of Champion International Corporation to Don R. Goodwin of EPA, dated June 13, 1977.
12. Standard Support and Environmental [illegible]ct Statement, Volume II: Promulgated Standards of Performance for Kraft Pulp Mills, EPA-450/2-76-014b, December, 1977.

APPENDIX A

SUMMARY OF KRAFT MILLS
IN THE UNITED STATES

	Company	Location	Mill Size Avg. Kraft Prod. (Kraft) (Cap.) tpd	No. of Units	Recovery Furnace Manuf.	Recovery Furnace Rating tpd	Year Instal.	Control[3] Tech-nique	TRS Level #/T ADP
Alabama									
	Allied Paper	Jackson	500 (408)	2	CE	566 350	post-1965 post-1965	BLO	0.5
	American Can	Bulter	930 (900)	3	B&W	390(each)	1965 1959,1956	BLO	0.5
	Champion	Courtland	500 (500)	1	B&W	500	1968	BLO	0.15
	Container Corp.	Brewton	900 (850)	2	B&W	390 600	1962 1969	BLO Low Odor	0.5
	Gerogia Kraft	Mahrt	1000 (975)	1	B&W	900	1965		0.5
	Gulf States	Demopolis	360 (400)	1	B&W	330	1955	BLO	0.5
	Gulf States	Tuscaloosa	500 (475)	2	B&W	175 250	1947 1941	BLO (oxygen)	0.5
	Hammermill	Selma	500 (500)	1	B&W	450		BLO	0.5
	I.P.	Mobile	1300 (1200)	2	B&W CE	700 900	1970 post-1965	BLO	0.5
	Kimberly-Clark	Coosa Pines	585 (600)	2				BLO	0.5
	MacMillan Bloedel	Pine Hill	1000 (975)	1	CE	932	post-1965	BLO	0.5
	Scott	Mobile	1400 (1400)	4	B&W	450;300 300	pre 1965	BLO	0.5
	Union Camp	Montgomery	870 (930)	1	CE	700	pre 1965	BLO	0.5
Arizona									
	Southwest Forest	Snowflake	600 (600)	2	B&W	250 500	1960 1969		15.0
Arkansas									
	Georgia-Pacific	Crossett	1250	3	CE	200&500 850	pre 1965 pre 1965	BLO	0.6
	Great Northern	Ashdown	400 (400)	1	CE	540	post-1965		15.0
	Green Bay	Morrilton	360	2	CE B&W	665 250	post-1965 1965		15.0
	I.P.	Camden	750 (750)	3	B&W	500 2-275	1966 1946		15.0
	I.P.	Pine Bluff	1220 (1300)	2	B&W	1100 390	1966 1959		15.0
	Weyerhaeuser	Pine Bluff	200 (200)	1	CE	165	pre 1965		15.0

[1] inc - incineration

[2] B - Batch
C - Continuous

[3] BLO - Black Liquor Oxidation

Lime Kiln No. of Units	Size Tons (CaO) Per Day	TRS Level[4] #/T ADP	Digester No.	Type[2] (Size)	Control[1] Technique	Level[4] #/T ADP	Multiple-effect Evaporator No.	Control Technique	TRS Level[4] #/T ADP	Brown Stock Washer No.	Capacity ADTPD	Washer Stages	TRS Level[4] #/T ADP
1	120	0.8	4	Batch	Inc.	0.02	1	Inc.	0.02	1		3	0.3
2	150 each	0.8	6	B	Inc.	0.02	2	inc.	0.02				
1	181	0.05	1	C (500 tpd)	Inc.	0.02	1	inc.	0.02				
2	120	0.8	8	B	Inc.	0.02	2	inc.	0.02	2		3 4	
1		0.8	1	C	Inc.	0.02	1	inc.	0.02	1		2	
1	120	0.8	1	C (400 tpd)	Inc.	0.02	1	inc.	0.02	1		3	
2	130 75	0.8	8	B (495)	Inc.	0.02	2	scrub.	0.08	2	300 475	3 4	
1	125	0.2	4	B (600)	Inc.	0.02	1	inc.	0.02	1	600	3	
		0.8			Inc.	0.02		Inc.	0.02				
2			6 1	B C (250)	Inc.	0.02		inc.	0.02				
1	225		1	C (925)	Inc.	0.02	1	inc.	0.02	2			
4	1400 (total)		13	B (910) C (500)	Inc.	0.02	4	inc.	0.02	5			
1	174		1	C (870)	Inc.	0.02	1	inc.	0.02	2			
2			6	B		1.5	2		1.0				
2	400		11	B (1276)	Inc.	0.02	4	Inc.	0.02	2			
1	117		4	B (400)		1.5	1		1.0	1		3	
1			2	B		1.5	1		1.0	1			
			2	C	Inc.	0.02			1.0				
						1.5			100				
1	150		3	B		1.5	1		1.0	1		3	

[4] Uncontrolled figures given are average uncontrolled figures for the industry unless actual level known, controlled levels given are actual figures when known otherwise state standard is given. Furnaces controlled with BLO but for which no state standard apply or actual level known, a level of 2.1 #/T (70 ppm) is assumed. A conversion table showirg the corresponding emission rate in terms of ppm and g/Kg ADP is presented at the end of the appendix.

					Recovery Furnace				
	Company	Location	Mill Size Avg. Kraft Prod. (Kraft) (Cap.) tpd	No. of Units	Manuf.	Rating tpd	Year Instal.	Control[3] Technique	TRS Level[4] #/T ADP
California	Crown Simpson	Fairhaven	550 (550)	1	B&W	800	1964	BLO	0.5
	Fibreboard	Antioch	890?	2	B&W	400	1959	BLO	0.6
	Louisiana-Pac.	Samoa	600 (700)	2	CE	350(each)	pre 1965	BLO	0.5
	Simpson Lee	Anderson	150 (160)	2	B&W	150 300	1962 1973	BLO Low Odor	6.5
Florida	Alton Box	Jacksonville	675 (650)	1	CE	750	post-1965	BLO	0.5
	Container Corp.	Fernandine Beach	1500 (1700)	2	B&W	1000 300	1967 1955	Low Odor BLO(Oxygen)	0.15
	Hudson P & P	Palatda	950 (950)	3	B&W CE	250(each) 1200	1950&1954 post-1965		0.5
	I. P.	Panama City	1400 (1400)	2	CE	900(each)	post-1965	BLO	0.5
	Proctor & Gamble	Foley	900 (900)	3	B&W CE	413&550 500	1952&1956 pre 1965		0.5
	St. Joe	Part St. Joe	1300 (1300)	3	CE	233&300 1060	pre 1965 post-1965		0.5
	St. Regis	Jacksonville	1350 (1400)	3	CE	300&383	pre-1965		0.5
	St. Regis	Pensacola	(920)	2	B&W	800(each)	1973	Low Odor	0.15
Georgia	Continental Can	Augusta	800 (800)	2	B&W	400(each)	1959&1964	BLO	0.6
	Continental Can	Port Hentworth	625 (600)	2	CE	350(each)			15.0
	Brunswick	Brunswick	1550 (1550)	2	B&W CE	1100 450	1970 pre 1965	Low Odor BLO	0.5
	Georgia Kraft	Krannert	1550 (1550)	3	CE	300&550 500	pre 1965 post-1965		15.0
	Georgia Kraft	Macon	900 (900)	2	CE	300	pre 1965		15.0
	Gilman	St. Mary	1100 (1000)	3	B&W CE	500 2-275	1968 pre 1965	BLO	15.0
	Great Northern	Cedar Springs	1780 (1700)	2	CE B&W	665 1000	pre 1965 1972	Low Odor Low Odor	0.5
	Interstate	Riceboro	525 (550)	1	B&W	450	1965		15.0
	Itt Rayonier	Jesup	1200 (1250)	3	B&W CE	1100 465&350	1970 pre 1965	Low Odor BLO	0.6

Lime Kiln No. of Units	Size Tons (CaO) Per Day	TRS Level[4] #/T ADP	Digester No.	Type[2] (Size)	Control[1] Tech-nique	Level[4] #/T ADP	Multiple-effect Evaporator No.	Control Tech-nique	TRS Level[4] #/T ADP	Brown Stock Washer No.	Capacity ADTPD	Washer Stages	TRS Level[4] #/T ADP
1		0.15	2	C	inc.	0.02	1	inc.	0.02				0.27
2		0.05	4	B	L.K. inc.	0.02		L.K. inc.	0.02	2	4		0.11
1	700	0.12	1	C (700)	L.K. inc.	0.02		L.K. inc.	0.02	1	2		0.19
1	50 (Fluo-solid)	0.05	1	C (170)	scrub	0.6		L.K. scrub	0.08				0.12
2	80 (each)	0.8	6	B (700)		1.5	2		1.0	1	3		0.3
2		0.8	7 1	B C		1.5	4		1.0	3			0.3
3		↓	13	B (1000)		↓	3		↓	4			↓
3		↓	19	B		↓	3		↓				↓
3	240	↓	10 1	B (1300) .C (500)		↓	3		↓				↓
3	280	↓	12	B		↓	3		↓				↓
3		0.2	18	B	inc.	0.02	4	inc.	0.02				↓
1 1	110 tlpd 70 tlpd (Fluo-solid)	0.8	2	C		1.5	2		1.0				↓
1	100	↓	9	B		↓	2		↓	3			↓
3	440	↓	17	B (1550)		↓	4		↓	4			↓
3	113 113 113	↓	14	B		↓	4		↓	4	4		↓
2	80 80	↓	8	B		↓	2		↓	2	4		↓
1	275	↓	13	B		↓			↓				↓
2	210 210	↓	10 1	B (1900) C (340)		↓	2		0.08				↓
1	111	↓	4 6	B B		↓	1		1.0				↓
3	144 144 212	↓	26	B					1 0				

	Company	Location	Mill Size Avg. Kraft Prod. (Kraft) (Cap.) tpd	No. of Units	Recovery Manuf.	Furnace Rating tpd	Year Insta.	Control[3] Tech-nique	TRS Level[4] #/T ADP
Georgia	Owens-Illinois	Valdosta	950	3	CE	350&250	pre-1965	BLO	2.1
	Union Camp	Savannah	2600 (2550)	6	CE	1350	post-1965 pre-1965	BLO	2.1
Idaho	Potlatch	Lewiston	850 (900)	4	CE B&W	150&300 300 400	pre-1965 1954 1970	BLO BLO Low Odor	0.5[6]
Kentucky	Western Kraft	Hawesville	300 (320)	2	B&W	225 300	1968 1974	BLO	0.15
	Westvaco	Wickliffe	600 (600)	1	CE	833	post-1965	BLO	0.5
Louisiana	Boise Cascade	DeRidder	1030 (1050)	1	B&W	1000	1968	BLO	0.6
	Boise Cascade	Elizabeth	300 (325)	1	B&W			BLO	2.1
	Continental Can	Hodge	1400 (1400)	2	B&W CE	300 1233	1955 post-1965	BLO	2.1
	Crown Zellerbach	Bogalvsa	1340 (1350)	2	B&W CE	800 350	1963 pre-1965	BLO	2.1
	Crown Zellerbach	St. Francisville	500 (500)	1	B&W	600	1963	BLO	2.1
	Georgia-Pacific	Port Hudson	530 (640)	2	B&W CE	690 1000	1965 post-1965	BLO	0.6
	I.P.	Bustrop	1100	2	CE B&W	300 1100	pre-1965 1966	BLO	2.1
	I.P.	Springhill	1000 1650	4	B&W CE	2-700;500 350	1973;66;62 pre-1965	BLO	0.6
	Olin	West Monroe	1125 (1150)	2	B&W B&W	450 800	1963 1974	BLO Low Odor	2.1
	Pineville	Pineville	800 (750)	1	CE	833	pre-1965	BLO	2.1
	Western Kraft	Campti	450	1	B&W	420	1972	Low Odor	C.15
Maine	Diamond Int.	Old Town	350 (550)	1	B&W	590	1969	Low Odor	0.15
	Georgia-Pacific	Woodland	800 (800)	2	B&W	350(each)	1963	BLO	0.5
	I.P.	Jay	600 (600)	2	B&W CE	800 600	1974 pre-1965	Low Odor BLO	0.15
	Lincoln	Lincoln	340 (400)	1	B&W	386	1970	Low Odor	0.15

Lime Kilns No. of Units	Size Tons (CaO) Per Day	TRS Level[4] #/T ADP	Digester No.	Type[2] (Size)	Control[1] Technique	Level[4] #/T ADP	Multiple-effect Evaporator No.	Control Technique	TRS Level[4] #/T ADP	Brown Stock Washer No.	Capacity ADTPD	Washer Stages	TRS Level[4] #/T ADP
3		0.8	9	B (950)		1.5	3		1.0	3		4	0.3
3	525	0.8	34 1	B (1775) C (600)		1.5	6		1.0				0.3
3	400	0.2	11 1	B (720) C	inc.	0.02	4	inc.	0.02				0.3
		0.2											
1	80		3	B (320)	inc.	0.02	1	inc.	0.02	1		3	0.3
1	60	0 0.05	1	C (600)	inc.	0.02	1	inc.	0.02	1		2	0.3
1		0.8	7	B		1.5	1		1.0				
1	75		6	B (300)		1.5	1		1.0	1			
2	471		3	C (1650)	inc.	0.02	2	inc.	0.02	4			
1			34 2	B (1250) C (250)		1.5	4		1.0				
			1	C	inc.	0.02		inc.	0.02				
1	150		1	C (660)	inc.	0.02	1	inc.	0.02	1		2	
			2	C	inc.	0.02			1.0				
						1.5			1.0				
1	300		4	C (1290)	inc.	0.02	2	inc.	0.02	4			
1	200		2	C ([illegible]40)	inc.	0.02	1	inc.	0.02	2		2	
		0.2											
		0 1	1	C	inc.	0.02			0.02				
1	150	0.8	1	C (600)	inc.	0.02	1	inc.	0.02				
		0.05	1	C (600)	inc.	0.02		inc.	0.02				0.02
1	100	0 1	1	C (400)	inc.	0.02	1	inc.	0.02	1		4	0.3

	Company	Location	Mill Size Avg. Kraft Prod. (Kraft) (Cap.) tpd	No. of Units	Recovery & Manuf.	Furnace Rating tpd	Year Instal.	Control[3] Technique	Level[4] #/T ADP
Maine									
	Oxford	Rumford	550 (560)	2	CE	300&200	pre-1965	BLO	0.5
	S. D. Warren	Westbrook	270 (300)	1	B&W	250	1962	BLO	0.5
Maryland									
	Westvaco	Luke	719 (647)	1	CE	1150	post-1965	BLO	0.6
Michigan									
	Mead	Escanaba	600 (600)	1	B&W	800	1969	Low Odor	0.15
	Scott	Muskegon	240 (225)	1	CE	240	pre-1965	BLO	2.1
Minnesota									
	Boise Cascade	Int'l Falls	320 (350)	2	CE B&W	150 550	pre-1965 1973		0.15
	Potlatch	Cloquet	400 (330)	1	B&W	400	1971	Low Odor	
Mississippi									
	I.P.	Moss Point	715	2	CE	330 523	pre-1965 post-1965	BLO	2.1
	I.P.	Natchez	1000 (1000)	3	CE B&W	900 600&250	post-1965 1963&1954		2.1
	I.P.	Vicksburg	1200 (1200)	1	B&W	1000	1965	BLO	2.1
	St. Regis	Monticello	1620 (1650)	2	CE	800(each)	post-1965	BLO	0.6
Montana									
	Hoerner-Waldorf	Missoula	1150 (1200)	2	B&W	1000 500	1970 1965	Low Odor Low Odor	0.5
New Hampshire									
	Brown	Berlin-Gorham	750 (750)	2	B&W CE	467 225	1965 pre-1965	BLO	2.1
N. York									
	I.P.	Ticonderoga	590 (460)	1	B&W	500	1968	Low Odor	0.15
N.Carolina									
	Champion	Canton	1360 (1360)	2	B&W	900(each)	1970&1963		2.1
	Federal	Riegelwood	1100 (1050)	3	CE	700 2-350	post-1965 pre-1965		15.0
	Hoerner-Waldorf	Roanoke Rapids	950 (950)	2	B&W CE	709 500	1972 pre-1965	Low Odor	15.0
	Weyerhaeuser	New Bern	640 (625)	1	CE	800	post-1965	Low Odor	0.15
	Weyerhaeuser	Plymouth	1350 (1500)	2	CE	1500 400	post-1965 pre-1965	Low Odor	0.15

Lime Kiln No. of Units	Lime Kiln Size Tons (CaO) Per Day	Lime Kiln TRS Level[4] #/T ADP	Digester No.	Digester Type[2] (Size)	Digester Control[1] Technique	Digester Level[4] #/T ADP	Multiple-effect Evaporator No.	Multiple-effect Evaporator Control Techniques	Multiple-effect Evaporator TRS Level[4] #/T ADP	Brown Stock Washer No.	Brown Stock Washer Capacity ADTPD	Brown Stock Washer Washer Stages	Brown Stock Washer TRS Level[4] #/T ADP
1	120	0.8	6	B (365)	inc.	0.02	1	inc.	0.02	2		4	0.3
1	90	0.8	7	B (315)	inc.	0.02	1	inc.	0.02	1		3	↓
		0.8	10	B	inc.	0.02		inc.	0.02				
1	220	0.05	6	B (700)	inc.	0.02	1	inc.	0.02	1		3	
1	70(Fluo-solids)	0.05	1	C (240)	inc.	0.02	1	inc.	0.02	1		3	
		0.05	5	B		1.5	1		1.0				
1	100	0.8	8	B (400)		1.5	1		1.0	2		3	
		0.05			inc.	0.02		inc.	0.02				
		0.05			inc.	0.02		inc.	0.02				
		0.05	2	C	inc.	0.02		inc.	0.02				
1	410	0.2	2	C (1650)	inc.	0.02	2	inc.	0.02	3			
3	300	0.8	3 8	C (900) B (700)	inc.	0.02	4	inc.	0.02				
2		0.8	9	B	inc. L.K	0.02	2		1.0	3		3	
1		0.05	1	C	inc.	0.02		inc.	0.02	1		2	0.02
2	300	0.8	18	B (1250)		1.5	3	scrub.	0.08	3		3	0.3
2	280	↓	11	B (10 each)		1.5	3		1.0				↓
1	.00		11	B (1000)		1.5	2		1.0	3		3	
1	225		7	B (800)	inc.	0.02	1	inc.	0.02	1		3	
3	315		231	B (1500)	inc.	1.5	5	inc.	1.0				

	Company	Location	Mill Size Avg. Kraft Prod. (Kraft) (Cap.) tpd	No. of Units	Recovery Furnace Manuf.	Recovery Furnace Rating tpd	Year Instal.	Control[3] Tech-nique	TRS Level[4] #/T ADP
Ohio									
	Grief	Massilon	(200)						15.0
	Mead	Chillicothe	600 (540)	2	CE	366 175	pre-1965 pre-1965	BLO	2.1
Oklahoma									
	Weyerhaeuser	Valliant	1300 (1300)	1	CE	1500	post-1965	Low Odor	0.15
Oregon									
	American Can	Halsey	300 (300)	1	B&W	400	1967	Low Odor	0.03
	Boise Cascade	St. Helens	850 (1150)	2	B&W CE	450 700	1966 1975	BLO Low Odor	0.3 0.0[illegible]
	Crown Z	Clatskanie	690 (916)	1	B&W	800	1964	BLO	0.1
	Georgie-Pacific	Toledo	1075 (1075)	3	CE	350(each)	1-post1965 2-pre1965	BLO	0.15
	I.P.	Gardiner	600 (545)	2	B&W CE	420 420	1972 pre-1965	Low Odor BLO	< 0.5
	Western Kraft	Albany	500 (550)	2	B&W	600 165	1969 1965	Low Odor	0.15
	Weyerhaeuser	Springfield	1150 (1050)	2	CE	800(each)	pre-1965 post-1965	BLO	0.15
Penna.									
	Appleton	Roaring Springs	180 (180)	2	B&W	122 83	1960 1950		15.0
	P.H. Glatfelter	Spring Grove	500 (500)	2	CE	400&150	pre-1965	BLO	2.1
				1	B&W	748	1969	Low Odor	
	Penntech	Johnsonburg	190 (130)	1	CE	160	pre-1965	BLO	2.1
S. Carolina									
	Bowater	Catawba	940 (940)	2	B&W	600 450	1964 1957	BLO	2.1
	I.P.	Georgetown	1830 (1750)	2	B&W	900(each)	1966 1963	BLO	0.5
	S. Carolina	Florence	660 (675)	2	B&W	1000 410	1972 1962	Low Odor	0.15
	Westvaco	Charleston	2000 (1909)	4	CE B&W	1000 360 250 250	pre-1965 1955 1948 1945	BLO	2.1

Lime Kilns			Digester				Multiple-effect Evaporator			Brown Stock Washer			
No. of Units	Size Tons (CaO) Per Day	TRS Level[4] #/T ADP	No.	Type[2] (Size)	Control[1] Tech-nique	Level[4] #/T ADP	No.	Control Tech-nique	TRS Level[4] #/T ADP	No.	Capacity ADTPD	Washer Stages	TRS Level[4] #/T ADP
		0.8				1.5			1.0				0.3
1	250	0.8	8	B (600)	inc.	0.02	2	scrub	0.08				0.3
1		0.8	3	C (1000) (500) (100)	inc.	0.02	1	inc.	0.02				0.3
1		0.15	2	C (300)	inc.	0.02	1	inc. L.K.	0.02	1	inc. R.F.	3	0.02
3		0.2	3 2	B C	inc.	0.02	2	inc.	0.02				0.3
1	250	0.05	2	C (916)	inc.	0.02	1	inc.	0.02	1	scrubber		0.002
3	260	0.05	11 1	B (650) C (115)	inc.	0.02	3	inc.	0.02	3		(2-3) (1-4)	0.02
		0.05			inc.	0.02		inc.	0.02				0.13
1		0.2	6	B	inc.	0.02	1	inc.	0.02	2			0.1
		0.1	7 1	B (380) C (770)	inc.	0.02		inc.	0.02		inc. Power boiler		0.02
1		0.8	5	B		1.5			1.0	1		4	
1 fluo-solid)		0.05	8	B (285) C (250)		1.5	2		1.0	2		3	
2	50	0.8	16	B (170)		1.5	1		1.0	1		3	
1		0.8	6	B (940)		1.5	2		1.0	1		4	
		0.8				1.5			1.0				
1	150	0.8	5	B (625)		1.5	1		1.0	2		(3,4)	
4	665	0.8	15 1	B (1800) C (700)	inc.	0.02	4	inc.	0.02				

	Company	Location	Mill Size Avg. Kraft Prod. (Kraft) (Cap.) tpd	No. of Units	Recovery Furnace Manuf.	Recovery Furnace Rating tpd	Year Instal.	Control[3] Tech-nique	TRS Level[4] #/T ADP
Tennessee	Bowater	Calhoun	500 (500)	2	CE	600&320	pre-1965	BLO	2.1
	Packaging	Counce	(775)	1	CE	420	post-1965		2.1
Texas	Champion	Pasadena	850 (820)	2	B&W	550 550	1971 1955	BLO	0.5
	I.P.	Texarkana	610	1	B&W	750	1969		0.5
	Owens-Illinois	Orange	1000 (900)	2	B&W	550(each)	1965	BLO (oxygen)	2.1
	Southland	Houston	650 (500)	1	CE	500	post-1965	BLO	2.1
	Southland	Lufkin	400 (400)	2	CE	175(each)	pre-1965		15.0
	Temple-Fostex	Evadale	1250 (1200)	3	B&W CE	534 1100 530	1966 post-1965 pre-1965	BLO	2.1
Virginia	Chesapeake	West Point	1150 (1150)	3	CE	900 400&200	post-1965 pre-1965	BLO	0.5
	Continental	Hopewell	896 (900)	2	CE	375(each)	pre-1965	BLO	0.5
	Union Camp	Franklin	1430 (1500)	3	CE	580 580&350	post-1965 pre-1965	BLO	0.5
	Westvaco	Covington	1048 (1000)	1	CE	1320	post-1965	BLO	0.5
Washington	Boise Cascade	Wallola	460 (460)	2	B&W	250 165	1960 1957	BLO	0.5
	Crown Zellerbach	Camas	780 (760)	2	B&W CE	350 660	1955 post-1965	BLO	0.5
	Crown Zellerbach	Port Townsend	420 (420)	1	CE	725	post-1965	Low Odor	0.5
	Longview	Longview	1600 (1900)	3	CE	1100 2-700	post-1965 pre-1965	BLO	0.5
	St. Regis	Tacoma	1090 (1040)	2	CE	863 467	post-1965 pre-1965	Low Odor BLO	0.5
	Weyerhaeuser	Everett	360 (375)	1	CE	365	post-1965	BLO	0.5

Lime Kilns No. of Units	Size Tons (CaO) Per Day	TRS Level[4] #/T ADP	Digester No.	Type[2] (Size)	Control[1] Technique	Level[4] #/T ADP	Multiple-effect Evaporator No.	Control Technique	TRS Level[4] #/T ADP	Brown Stock Washer No.	Capacity ADTPD	Washer Stages	TRS Level[4] #/T ADP
1		0.8	6	B (500)	inc.	0.02	1	inc.	0.02	1		4	0.3
		0.8	5	B		1.5			1.0				
3	350	0.05	9	B 100 each	inc.	0.02	2	inc.	0.02				
		-0.2	5	B	inc.	0.02		inc.	0.02				
1	260	0.8	2	C (1000)		1.5	1		1.0				
1	130	0.8	1	C (500)		1.5	1		1.0	1			
1	85	0.8	6	B (400)		1.5	2		1.0				
3	360	0.8	9 1	B(1200) C (200)		1.5	3		1.0				
2	300	0.8	8 1	B (600) C (600)		0.02	3		0.02				
3	445 (total)	0.8	13 2	B (900) C (230)		0.02	2		0.02	4			
3	400 (total)	0.8	12 2	B (950) C (800)		0.02	4		0.02	3			
		0.8	10	B		0.02			0.02				
2		0.2	5 1	B C (150)	inc.	0.02	2	inc.	0.02				
3	200	0.2	9 1	B C	inc.	0.02	3	inc.	0.02				
		0.2	9 1	B C	Power inc.	0.02		inc.	0.02				
4	500	0.2	18 4	B (1600) C (600)	inc.	0.02	6	inc.	0.02				
2	196 & 80	0.2	4 2	B (240) C (690)	inc.	0.02	2	inc.	0.02	3		3	
1	140	0.2	6	B (550)	inc.	0.02	1	inc.	0.02				

	Company	Location	Mill Size Avg. Kraft Prod. (Kraft) (Cap.) tpd	No. of Units	Recovery Furnace Manuf.	Rating tpd	Year Instal.	Control[3] Technique	TRS Level[4] #/T ADP
Washington	Weyerhaeuser	Longview	650 (306) NSSC	2	B&W CE	1200 350	1972 pre-1965	Low Odor BLO	0.5
Wisconsin	Consolidated	Wisc. Rapids	ch. rec. plant 400 (400)	2	CE	400(each)	post-1965	BLO	0.5
	Great Northern	Nekoosa	ch. rec. plant 310 (330)	2	CE	350 165	pre-1965 pre-1965		0.5
	Hammermill	Kaukauna	ch. rec. plant 400 (400)	1	B&W	390	1960	BLO	0.5
	Mosinee	Mosinee	174 (175)	1	B&W	250	1973	Low Odor	0.5

New Mills (Planned or under construction)

Scott Paper - Skowhegan, Maine - 750 TPD
Potlatch Corp. - McGehee, Arkansas - 500 TPD.

Lime Kilns No. of Units	Size Tons (CaO) Per Day	TRS Level[4] #/T ADP	Digester No.	Type[2] (Size)	Control[1] Technique	Level[4] #/T ADP	Multiple-effect Evaporator No.	Control Technique	TRS Level[4] #/T ADP	Brown Stock Washer No.	Capacity ADTPD	Washer Stages	TRS Level[4] #/T ADP
		0.2	12 1	B C	inc.	0.02		inc.	0.02	3			0.3
		0.8	2	C scrubber		1.1			1.0				
		0.8	9	B		1.5			1.0				
		0.8	6	C		1.5			1.0				
		0.6	6	B (175)		1.5	1		1.0	3			

CONVERSION TABLE

Source	Emission Rate lb/T ADP	Emission Rate g/Kg ADP	ppm
Recovery Furnace	0.15	0.075	5
	0.5	0.25	17.5
	0.6	0.3	20
	2.1	1.05	70
	15.0	7.5	550
Lime Kiln	0.05	0.025	10
	0.1	0.05	20
	0.2	0.1	40
	0.8	0.4	170
Digester	0.01	0.05	<5
	1.1	0.55	7000
	1.5	0.75	9500
Multiple-effect Evaporator	0.01	0.05	<5
	0.08	0.04	350
	1.0	0.5	6700
Brown Stock Washer	0.01	0.05	<5
	0.3	0.15	30

APPENDIX B

DATA SUMMARY

KRAFT PULP MILLS

Recovery Furnaces, Smelt Dissolving Tanks, Lime Kilns, and Incinerators

Results are summarized for tests conducted by EPA at 6 kraft pulp mills. At these mills a total of 9 TRS tests; 3 recovery furnaces, 2 smelt dissolving tanks, 3 lime kilns, and one incinerator, were conducted by EPA. Emission data obtained from operators or state agencies are also reported for some of the facilities.

TRS EMISSION DATA

Incinerator:

The incinerator handles the noncondensable gases from a continuous digester system and a multiple-effect evaporator system. The continuous digester was producing 670 tons of pulp per day. The incinerator was operating at 1000°F with a retention time for the gases of at least 0.5 seconds. Natural gas is fired in the incinerator.

Recovery Furnaces:

A. Conventional type recovery furnace designed for an equivalent pulp production rate of 657 tons per day. TRS emissions are controlled by using black liquor oxidation and maintaining proper furnace operation. The furnace was operating near its design capacity during the EPA test period. Continuous monitoring data were also obtained from the operator.

B. Low-odor type recovery furnace designed for an equivalent pulp production of 300 tons per day. During the EPA testing, the furnace was operating at a rate of about 345 tons of pulp per day. TRS emissions are controlled by eliminating the direct contact evaporator and maintaining proper furnace operation. Noncondensable gases from the brown stock washer system are burned in this furnace. Continuous monitoring data were also obtained from the state agency.

D. Conventional type recovery furnace designed for an equivalent pulp production rate of 602 tons per day. TRS emissions are controlled by black liquor oxidation and maintaining proper furnace operation.

H. Low-odor type recovery furnace operating at an equivalent pulp production rate of about 200 tons per day. TRS emissions are controlled by maintaining proper furnace operation. Data were obtained from the state agency.

K. Low-odor type recovery furnace designed for an equivalent pulp production rate of about 863 tons per day. TRS emissions are controlled by maintaining proper furnace operation. Data were obtained from state agency.

Smelt Dissolving Tanks

D. A wet fan type scrubber is employed to control the particulate emissions. Weak wash liquor is used as the scrubbing medium. The associated recovery furnace operates at an equivalent pulp production rate of 570 tons per day.

E. A wet fan type scrubber is employed to control the particulate emissions. Fresh water is used as the scrubbing medium. The associated recovery furnace operates at an equivalent pulp production rate of 770 tons per day.

Lime Kilns

D. Rotary lime kiln operating at an equivalent pulp production rate of 570 tons per day. TRS emissions are controlled by maintaining proper kiln combustion and proper lime mud washing. Noncondensable gases from the multiple-effect evaporators are burned in the kiln.

E. Rotary lime kiln operating at an equivalent pulp production rate of about 770 tons per day. TRS emissions are controlled by maintaining proper combustion in the kiln, maintaining proper lime mud washing, and using a caustic solution in the particulate scrubber. Noncondensable gases from the digesters, multiple-effect evaporators, condensate stripper, and miscellaneous storage tanks are burned in the kiln. Continuous monitoring data were also obtained from the operator.

K. Rotary lime kiln operating at an equivalent pulp production rate of about 320 tons per day. TRS emissions are controlled by maintaining proper combustion in the kiln and proper lime mud washing. Noncondensable gases from the digesters, multiple-effect evaporators, and turpentine system are burned in the kiln.

O. Rotary lime kiln not tested by EPA. Continuous monitoring data was obtained from the local agency. TRS emissions are controlled by maintaining process combustion in the kiln.

Table B-1 - TRS and SO_2 Emissions from Incineration

FACILITY - Incinerator

Summary of Results

Run Number	1	2	3	4
Date - 1972	10/5	10/6	10/7	12/13
Test Time - minutes	240	240	240	240
Production Rate - TPH	-	-	-	-
Stack Effluent				
Flow rate - DSCFM (X1000)	2610	2223	2302	-
Flow rate - DSCF/ton	-	-	-	-
Temperature - °F	805	805	805	-
Water vapor - Vol. %	6.3	4.3	5.4	-
CO_2 - Vol. % dry	2.6	2.4	2.1	9.0
O_2 - Vol. % dry	11.8	12.0	12.7	15.7
CO - ppm	0	0	0	0
TRS Emissions				
ppm	2.8	0.4	1.6	0.9
lb/hr	1.5	0.2	0.6	0.4
lb/ton of pulp	0.06	0.007	0.02	0.02
SO_2 Emissions				
ppm	25	306	1050	-
lb/hr	9.4	96.9	358	-
lb/ton of pulp	0.4	3.8	13.9	-

Table B-2 - TRS and SO_2 Emissions from Recovery Furnace A

FACILITY - Recovery Furnace A

Summary of Results

Run Number	1	2	3	4	5	6
Date - 1972	6/3	6/4	6/5	6/6	6/7	6/8
Test Time - minutes	240	240	240	240	240	240
Production Rate - TPH	-	-	-	-	-	-
Stack Effluent						
Flow rate - DSCFM (X1000)	142	-	145	148	-	-
Flow rate - DSCF/ton	-	-	-	-	-	-
Temperature - °F	314	-	304	303	-	-
Water vapor - Vol. %	25.5	-	25.3	21.9	-	-
CO_2 - Vol. % dry	10.4	8.2	10.7	11.8	12.9	11.1
O_2 - Vol. % dry	10.7	11.4	11.4	10.1	10.1	9.9
CO - ppm	153	93	84	95	102	51
TRS Emissions						
ppm	2.0	1.4	1.4	1.5	0.7	1.6
lb/hr	1.5	1.1	1.1	1.2	0.6	1.2
lb/ton of pulp	-	-	-	-	-	-
SO_2 Emissions						
ppm	45	116	79	118	50	119
lb/hr	85.0	-	-	-	-	-
lb/ton of pulp	-	-	-	-	-	-

Table B-3 - TRS and SO_2 Emissions from Recovery Furnace B

FACILITY - Recovery Furnace B

Summary of Results

Run Number	1	2	3	4	5	6
Date - 1972	7/13	7/14	7/15	7/18	7/19	7/20
Test Time - minutes	240	240	240	240	240	240
Production Rate - TPH	-	-	-	-	-	-
Stack Effluent						
Flow rate - DSCFM (X1000)	85	84	86	-	-	-
Flow rate - DSCF/ton	-	-	-	-	-	-
Temperature - °F	395	400	415	-	-	-
Water vapor - Vol. %	-	-	-	-	-	-
CO_2 - Vol. % dry	-	12.3	12.4	12.7	12.0	12.4
O_2 - Vol. % dry	-	8.1	7.6	7.7	8.0	8.0
CO - ppm	0	0	0	0	0	0
TRS Emissions						
ppm	1.6	0.2	0.5	0.3	0.4	0.3
lb/hr		0.7	0.1	0.2	0.2	0.2
lb/ton of pulp *	.05	.01	.02	.01	.01	.01
SO_2 Emissions						
ppm	0.9	-	-	-	-	-
lb/hr	-	-	-	-	-	-
lb/ton of pulp	-	-	-	-	-	-

* Based on 334.5 ATDP/day

Table B-4- TRS and SO_2 Emissions from Recovery Furnace D

FACILITY - Recovery Furnace D

Summary of Results

Run Number	1	2	3	4	5
Date - 1972	11/11	11/12	11/13	11/14	11/15
Test Time - minutes	240	240	240	240	240
Production Rate - TPH	-	-	-	-	-
Stack Effluent					
Flow rate - DSCFM (X1000)	73.2	73.2	73.2	73.2	73.2
Flow rate - DSCF/ton					
Temperature - °F					
Water vapor - Vol. %	35	35	35	35	35
CO_2 - Vol. % dry					
O_2 - Vol. % dry					
CO - ppm					
TRS Emissions					
ppm	3.1	2.8	3.9	7.0	2.8
lb/hr	55.1	48.9	53.7	12.5	46.0
lb/ton of pulp	-	-	-	-	-
SO_2 Emissions					
ppm	15.5	1.0	22.9	5.0	14.2
lb/hr	162	10	239	52	149
lb/ton of pulp	-	-	-	-	-

Table B-5

ADDITIONAL TRS EMISSION DATA FOR RECOVERY FURNACES*

	Recovery Furnace A TRS Concentration (ppm, daily average basis)			Recovery Furnace B TRS Concentration (ppm, daily average basis)	
Month	Maximum	Average	Month	Maximum	Average
July 1971	6.0	3.1	April 1972	1.4	0.7
Aug.	20.0	2.4	May	2.3	1.2
Sept.	5.0	1.5	June	2.8	1.5
Oct.	10.9	2.8	July	4.6	1.1
Nov.	4.4	1.3	Aug.	5.0	1.5
Dec.	9.8	1.8	Oct.	1.9	0.7
Jan. 1972	5.5	1.6	Nov.	0.7	0.4
Feb.	3.3	1.3	Dec.	1.0	0.7
March	2.5	1.0	Jan. 1973	1.5	0.8
April	5.3	2.0	Feb.	2.6	1.0
May	5.5	2.1	March	2.4	0.9
June	8.2	3.8	April	1.5	0.8
July	9.8	3.7	May	1.6	1.0
Aug.	9.0	3.3	June	1.9	1.1
Sept.	4.9	2.9	July	1.6	1.0
Oct.	6.1	2.2	Aug.	3.1	1.2
			Sept.	1.8	0.8
			Oct.	2.0	0.9
			Nov.	1.6	0.8
			Dec.	3.4	1.6

*Tested by operators using barton titrators.

Table B-5 (cont.)

ADDITIONAL TRS EMISSION DATA FOR RECOVERY FURNACES

	Recovery Furnace A TRS Concentration (ppm, daily average basis)	
Month	Maximum	Average

	Recovery Furnace B TRS Concentration (ppm, daily average basis)	
Month	Maximum	Average
Jan. 1974	1.4	0.8
Feb.	1.9	1.3
March	5.0	1.6
April	2.4	1.2
May	1.8	1.0
June	1.5	1.0

	Recovery Furnace H TRS Concentration (ppm, daily average basis)	
Month	Maximum	Average
April 1972	3	2.1
May	4	2.1
June	7	3.5
June 1972	8	3.1
July	4	2.4
Aug.	4	1.9
Sept.	2	1.3
Oct.	6	1.8

	Recovery Furnace K TRS Concentration (ppm, daily average basis)	
Month	Maximum	Average
Aug. 1973	6.2	1.0
Sept.	32.0	5.2
Oct.	7.3	2.4
Nov.	17.0	4.1
Dec.	1.2	0.7
Jan. 1974	1.8	0.6
Feb.	2.4	1.0
March	9.7	2.3
April	3.0	1.4
May	3.4	1.4

Table B-6

TRS EMISSION DATA FOR A CROSS RECOVERY FURNACE*

Month	Sulfidity Range (%)	Average TRS Emissions (ppm)	Maximum 4-Hour TRS Emissions (ppm)	Days TRS (4-hour) Emissions Greater than 25 ppm
Oct 76	22 - 36	12.5	54.5	2
Nov 76	28 - 33	24.3	51.2	4
Dec 76	28 - 34	9.5	43.2	1
Jan 77	27 - 36	7.7	36.5	0
Feb 77	27 - 35	8.0	48.0	1

* Tested by operator using barton tatrator.

TableB-7 - TRS Emissions from Smelt Dissolving Tank D

FACILITY - Smelt Dissolving Tank D

Summary of Results

Run Number	1	2	3
Date - 1973	10/31	11/1	11/2
Test Time - minutes	240	240	240
Production Rate - TPH	25.1	25.9	25.6
Stack Effluent			
Flow rate - DSCFM	9000	8880	9400
Flow rate - DSCF/ton	21514	20571	22031
Temperature - °F			
Water vapor - Vol. %	37	41	40
CO_2 - Vol. % dry			
O_2 - Vol. % dry			
CO - ppm			
TRS Emissions			
ppm	8.1	8.8	6.9
lb/hr	0.43	0.44	0.38
lb/ton of pulp	0.017	0.017	.015

Table B-8- TRS Emissions from Smelt Dissolving Tank E

FACILITY - Smelt Dissolving Tank E

Summary of Results

Run Number	1	2	3
Date - 1973	9/18	9/19	9/20
Test Time - minutes	240	240	240
Production Rate - TPH	30.1	34.1	31.3
Stack Effluent			
Flow rate - DSCFM	19542	18740	19100
Flow rate - DSCF/ton	38954	32974	36613
Temperature - °F			
Water vapor - Vol. %	26	26	23.3
CO_2 - Vol. % dry			
O_2 - Vol. % dry			
CO - ppm			
TRS Emissions			
ppm	2.4	1.9	2.7
lb/hr	0.27	0.20	0.28
lb/ton of pulp	0.009	.006	.009

Table B-9 - TRS Emissions from Lime Kiln D

FACILITY - Lime Kiln D

Summary of Results

Run Number	1	2	3	4	5	6
Date - 1973	11/5	11/7	11/7	11/7	11/8	11/8
Test Time - minutes	240	240	240	240	240	240
Production Rate - TPH						
Stack Effluent						
Flow rate - DSCFM (X1000)						
Flow rate - DSCF/ton						
Temperature - °F						
Water vapor - Vol. %	43	35	40	38	41	31
CO_2 - Vol. % dry						
O_2 - Vol. % dry						
CO - ppm						
TRS Emissions						
ppm	3.5	24.1	2.8	5.7	4.6	17.8
lb/hr						
lb/ton of pulp						

Table B-10- TRS Emissions from Lime Kiln E

FACILITY - Lime Kiln E

Summary of Results

Run Number	1	2	3	4	5	6
Date - 1973	9/24	9/25	9/26	9/26	9/27	9/27
Test Time - minutes	240	240	240	240	240	240
Production Rate - TPH						
Stack Effluent						
Flow rate - DSCFM (X1000)						
Flow rate - DSCF/ton						
Temperature - °F						
Water vapor - Vol. %						
CO_2 - Vol. % dry	9.4	10.2	10.0	9.8	8.2	9.8
O_2 - Vol. % dry	13.2	11.0	12.2	12.0	13.1	11.8
CO - ppm						
TRS Emissions						
ppm	1.7	0.8	0.5	0.4	0.3	0.5
lb/hr						
lb/ton of pulp						

Table B-11-TRS and SO_2 Emissions from Lime Kiln K

FACILITY - Lime Kiln K

Summary of Results

Run Number	1	2	3	4	5	6
Date - 1974	4/5	4/5	4/9	4/9	4/10	4/10
Test Time - minutes	240	240	240	240	240	240
Production Rate - TPH	-	-	-	-	-	-
Stack Effluent						
Flow rate - DSCFM (X1000)	13.8	13.8	14.0	13.4	13.6	14.2
Flow rate - DSCF/ton	-	-	-	-	-	-
Temperature - °F	142	142	146	152	155	154
Water vapor - Vol. %	21.8	21.8	22.9	26.0	25.8	26.8
CO_2 - Vol. % dry	13.0	13.0	14.2	14.2	14.6	14.2
O_2 - Vol. % dry	7.6	7.6	7.1	7.1	6.4	7.2
CO - ppm	0	0	0	0	0	0
TRS Emissions						
ppm	4.6	12.0	4.5	4.8	4.0	5.2
lb/hr	0.34	0.88	0.33	0.34	0.29	0.39
lb/ton of pulp	-	-	-	-	-	-
SO_2 Emissions						
ppm	52	42	25	18	16	37
lb/hr	7.2	5.8	3.5	2.4	2.2	5.2
lb/ton of pulp	-	-	-	-	-	-

Table B-12

ADDITIONAL TRS EMISSION DATA FOR LIME KILNS*

	Lime Kiln E TRS Concentration (ppm, daily average)			Lime Kiln O TRS Concentration (ppm, daily average)	
Month	Maximum	Average	Month	Maximum	Average
May 1973	1.4	0.3	Jan. 1973	14	6.8
June	3.4	0.7	Feb.	20	9.3
July	2.1	0.4	March	14	7.6
Aug.	1.4	0.3	April	32	9.6
Sept.	10.1	1.5	May	16	4.7
Oct.	7.1	1.0	June	10	3.4
Nov.	5.9	0.8	July	9	4.5
Dec.	8.9	1.0	Aug.	12	3.8
Jan. 1974	3.4	0.6	Sept.	17	5.0
Feb.	2.6	0.2	Oct.	34	8.2
March	0.7	0.1	Nov.	12	5.7
April	3.1	0.6	Dec.	22	9.8
May	2.9	0.7	Jan. 1974	30	17.9
			Feb.	33	21.1
			March	30	19.3
			April	40	16.2
			May	25	12.3
					Average = 9.7

*Tested by operators using barton titrators.

Table B-12 (CONTINUED)

Lime Kiln P

TRS Summary: 4-Hour Averages

Month	4-Hour Averages Monitored % <5 ppm	% >5/ <10 ppm	% >10/ <20 ppm	% >20 ppm	% >40 ppm
February '75	45	26	9	20	12
March '75	65	25	7	7	2
April '75	63	16	12	9	5
May '75	53	25	13	8	2

APPENDIX C

DISPERSION STUDIES

TABLE C-1

IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES ON
AMBIENT TRS CONCENTRATION FROM A 907 MEGAGRAMS/DAY
KRAFT PULP MILL

		Maximum Ambient Concentration: $\mu g/m^3$ (One-hour average)						Frequency - % of Concentrations Greater than 1/2 the Maximum	Percent Reduction[a]
		Uncontrolled Level @ 0.3 km	Distance from Source (km)						
Source	Control Techniques		0.3	0.6	1.0	1.5	2.0		
Recovery Furnace	BLO (20 ppm)	2465	100	64	38		16	28	95.9
	BLO (5 ppm)	2465	25	16	10		4	28	99.0
Digester	Scrubber	6000	4680	1716	1090			3	22.0
	Incineration	6000	0[b] →	→	→	→	→	-	100.0
Multiple-Effect Evaporator	Scrubber	1175	96	60	36			4	91.8
	Incineration	1175	0[b] →	→	→	→	→	-	100.0
Lime Kiln	1) Process Controls	256	64	23	18	15	12	1	75.0
	2) Process Controls + High Eff. Mud Washing	256	16	6	4	4	3	1	93.8
	3) Process Controls + High Eff. Mud Washing + Caustic Scrubbing	256	8	3	2	2	2	1	96.9
Brown Stock Washer System	Incineration	113	8		3	2		34	92.9
Black Liquor Oxidation System	Incineration	96	19	6	3	1	1	25	80.2
	Molecular Oxygen	96	0[c] →	→	→	→	→	-	100.0
Smelt Dissolving Tank	Fresh Water	172	22		8	6		3	87.2
Condensate Stripping System	Scrubber	4400	2200		306	165		25	50.0
	Incineration	4400	0[b] →	→	→	→	→	-	100.0

[a] Reduction from uncontrolled average level

[b] Gases are assumed burned in the lime kiln. The levels from the lime kiln include unburned TRS portion of these gases.

[c] No vent gases.

TABLE C-2

IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES ON AMBIENT TRS CONCENTRATION FROM A 907 MEGAGRAMS/DAY KRAFT PULP MILL

Source	Control Techniques	Maximum Ambient Concentration: μg/m³ (24-hour average)						Frequency - % of Concentrations Greater than 1/2 the Maximum	Percent Reduction[a]
		Uncontrolled Level @ 0.3 km	Distance from Source (km) 0.3	0.6	1.0	1.5	2.0		
Recovery Furnace	BLO (20 ppm)	643	26	16	9		4	29	96.0
	BLO (5 ppm)	643	6	4	2		1	29	99.0
Digester	Scrubber	580	450	150	68			48	22.4
	Incineration	580	0[b] →					--	100.0
Multiple-Effect Evaporator	Scrubber	115	10	6	3			55	91.3
	Incineration	115	0[b] →					--	100.0
Lime Kiln	1) Process Controls	56	14	7	4	3	2	1	75.0
	2) Process Controls + High Eff. Mud Washing	56	4	2	1	1	1	1	92.9
	3) Process Controls + High Eff. Mud Washing + Caustic Scrubbing	56	2	1	1	1	1	1	96.4
Brown Stock Washer System	Incineration	30	2		1	1		26	93.3
Black Liquor Oxidation System	Incineration	25	5	2	1	1	1	20	80.0
	Molecular Oxygen	25	0[c] →					--	100.0
Smelt Dissolving Tank	Fresh Water	16	2		1	1		46	87.5
Condensate Stripping System	Scrubber	840	420		66	34		30	50.0
	Incineration	840	0[b] →					--	100.0

[a] Reduction from uncontrolled average level

[b] Gases are assumed burned in the lime kiln. The levels from the lime kiln include unburned TRS portion of these gases.

[c] No vent gases.

TABLE C-3

IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES ON AMBIENT TRS CONCENTRATION FROM A 454 MEGAGRAMS/DAY KRAFT PULP MILL

Source	Control Techniques	Maximum Ambient Concentration: μg/m^3 (10 second average) Uncontrolled Level @ 0.3 km	Distance from Source (km) 0.3	0.6	1.0	1.5	2.0	Frequency - % of Concentrations Greater than 1/2 the Maximum	Percent Reduction[a]
Recovery Furnace	BLO (20 ppm)	5250	210	135	80		34	33	96.0
	BLO (5 ppm)	5250	53	35	20		8	33	99.0
Digester	Scrubber	9800	7645	2790	1775			3	22.0
	Incineration	9800	0[b] →	→	→	→	→	-	100.0
Multiple-Effect Evaporator	Scrubber	1950	156	98	58			4	92.0
	Incineration	1950	0[b] →	→	→	→	→	-	100.0
Lime Kiln	1) Process Controls	440	110	40	30	25	21	1	75.0
	2) Process Controls + High Eff. Mud Washing	440	28	10	8	6	5	1	93.6
	3) Process Controls + High Eff. Mud Washing + Caustic Scrubbing	440	14	5	4	3	3	1	96.8
Brown Stock Washer System	Incineration	370	25		9	6		19	93.2
Black Liquor Oxidation System	Incineration	210	42	14	7	3	3	30	80.0
	Molecular Oxygen	210	0[c] →	→	→	→	→	--	100.0
Smelt Dissolving Tank	Fresh Water	270	34		13	8		3	87.4
Condensate Stripping System	Scrubber	9100	4550		635	340		16	50.0
	Incineration	9100	0[b] →	→	→	→	→	--	100.0

[a] Reduction from uncontrolled average level

[b] Gases are assumed burned in the lime kiln. The levels from the lime kiln include unburned TRS portion of these gases.

[c] No vent gases.

TABLE C-4

IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES ON AMBIENT TRS CONCENTRATION FROM A 454 MEGAGRAMS/DAY KRAFT PULP MILL

Source	Control Techniques	Uncontrolled Level @ 0.3 km	Maximum Ambient Concentration: μg/m^3 (One-hour average) Distance from Source (km) 0.3	0.6	1.0	1.5	2.0	Frequency - % of Concentrations Greater than 1/2 the Maximum	Percent Reduction[a]
Recovery Furnace	BLO (20 ppm)	1610	64	41	24		10	33	96.0
	BLO (5 ppm)	1610	16	10	6		3	33	99.0
Digester	Scrubber	3000	2340	860	545			3	22.0
	Incineration	3000	0[b] →	→	→	→	→	-	100.0
Multiple-Effect Evaporator	Scrubber	600	48	30	18			4	92.0
	Incineration	600	0[b] →	→	→	→	→	-	100.0
Lime Kiln	1) Process Controls	136	34	12	9	8	7	1	75.0
	2) Process Controls + High Eff. Mud Washing	136	9	3	3	2	2	1	93.4
	3) Process Controls + High Eff. Mud Washing + Caustic Scrubbing	136	5	2	1	1	1	1	96.3
Brown Stock Washer System	Incineration	113	8		3	2		19	92.9
Black Liquor Oxidation System	Incineration	66	13	4	2	1	1	30	80.3
	Molecular Oxygen	66	0[c] →	→	→	→	→	-	100.0
Smelt Dissolving Tank	Fresh Water	84	11		4	3		3	86.9
Condensate Stripping System	Scrubber	2800	1400		195	105		16	50.0
	Incineration	2800	0[b] →	→	→	→	→	-	100.0

[a] Reduction from uncontrolled average level

[b] Gases are assumed burned in the lime kiln. The levels from the lime kiln include unburned TRS portion of these gases.

[c] No vent gases.

TABLE C-5

IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES ON AMBIENT TRS CONCENTRATION FROM A 454 MEGAGRAMS/DAY KRAFT PULP MILL

		Maximum Ambient Concentration: μg/m^3 (24-hour average)							
		Uncontrolled	Distance from Source (km)					Frequency - % of Concentrations Greater than 1/2	
Source	Control Techniques	Level @ 0.3 km	0.3	0.6	1.0	1.5	2.0	the Maximum	Percent Reduction[a]
Recovery Furnace	BLO (20 ppm)	430	17	11	6		2	27	96.0
	BLO (5 ppm)	430	4	3	1		1	27	99.1
Digester	Scrubber	290	226	76	34			48	22.1
	Incineration	290	0[b] →					-	100.0
Multiple-Effect Evaporator	Scrubber	60	5	3	2			55	91.7
	Incineration	60	0[b] →					-	100.0
Lime Kiln	1) Process Controls	32	8	4	2	2	1	4	75.0
	2) Process Controls + High Eff. Mud Washing	32	2	1	1	1	1	4	93.8
	3) Process Controls + High Eff. Mud Washing + Caustic Scrubbing	32	1	1	<1	<1	<1	4	96.9
Brown Stock Washer System	Incineration	17	1		1	1		52	94.1
Black Liquor Oxidation System	Incineration	17	3	1	1	<1	<1	19	82.4
	Molecular Oxygen	17	0[c] →					-	100.0
Smelt Dissolving Tank	Fresh Water	8	1		1	1		46	
Condensate Stripping System	Scrubber	420	210		28	17		37	50.0
	Incineration	420	0[b] →					-	100.0

[a] Reduction from uncontrolled average level

[b] Gases are assumed burned in the lime kiln. The levels from the lime kiln include unburned TRS portion of these gases.

[c] No vent gases.

TABLE C-6

IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES ON AMBIENT TRS CONCENTRATION FROM A 1350 MEGAGRAMS/DAY KRAFT PULP MILL

Source	Control Techniques	Uncontrolled Level @ 0.3 km	Maximum Ambient Concentration: µg/m^3 (10 second average) Distance from Source (km) 0.3	0.6	1.0	1.5	2.0	Frequency - % of Concentrations Greater than 1/2 the Maximum	Percent Reduction[a]
Recovery Furnace	BLO (20 ppm)	11,785	470	305	180		75	28	96.0
	BLO (5 ppm)	11,785	120	75	45		20	28	99.0
Digester	Scrubber	29,000	22,930	8370	5325			3	20.9
	Incineration	29,000	0[b] →					-	100.0
Multiple-Effect Evaporator	Scrubber	5,750	470	295	175			4	91.8
	Incineration	5,750	0[b] →					-	100.0
Lime Kiln	1) Process Controls	1,280	320	115	88	73	62	1	75.0
	2) Process Controls + High Eff. Mud Washing	1,280	80	29	22	18	16	1	93.8
	3) Process Controls + High Eff. Mud Washing + Caustic Scrubbing	1,280	40	14	11	9	8	1	96.9
Brown Stock Washer System	Incineration	555	37		14	9		34	93.3
Black Liquor Oxidation System	Incineration	490	98	33	14	7	5	25	80.0
	Molecular Oxygen	490	0[c] →					-	100.0
Smelt Dissolving Tank	Fresh Water	840	105		39	24		3	87.5
Condensate Stripping System	Scrubber	21,000	10,500		1460	780		25	50.0
	Incineration	21,000	0[b] →					-	100.0

[a] Reduction from uncontrolled average level

[b] Gases are assumed burned in the lime kiln. The levels from the lime kiln include unburned TRS portion of these gases.

[c] No vent gases.

TABLE C-7

IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES ON AMBIENT TRS CONCENTRATION FROM A 1350 MEGAGRAMS/DAY KRAFT PULP MILL

Source	Control Techniques	Maximum Ambient Concentration: μg/m³ (One-hour average) Uncontrolled Level @ 0.3 km	Distance from Source (km) 0.3	0.6	1.0	1.5	2.0	Frequency - % of Concentrations Greater than 1/2 the Maximum	Percent Reduction[a]
Recovery Furnace	BLO (20 ppm)	3,750	150	97	57		24	28	96.0
	BLO (5 ppm)	3,750	37	24	14		6	28	99.0
Digester	Scrubber	9,000	7,020	2,575	1,640			3	22.0
	Incineration	9,000	0[b] →					-	100.0
Multiple-Effect Evaporator	Scrubber	1,775	154	90	53			4	91.3
	Incineration	1,775	0[b] →					-	100.0
Lime Kiln	1) Process Controls	385	96	34	27	22	19	1	75.0
	2) Process Controls + High Eff. Mud Washing	385	24	9	6	6	5	1	93.8
	3) Process Controls + High Eff. Mud Washing + Caustic Scrubbing	385	12	4	3	3	2	1	96.9
Brown Stock Washer System	Incineration	175	12		4	3		34	94.8
Black Liquor Oxidation System	Incineration	150	30	10	5	2	2	25	80.0
	Molecular Oxygen	150	0[c] →					-	100.0
Smelt Dissolving Tank	Fresh Water	255	32		12	9		3	87.5
Condensate Stripping System	Scrubber	6,600	3,300		460	250		25	50.0
	Incineration	6,600	0[b] →					-	100.0

[a] Reduction from uncontrolled average level

[b] Gases are assumed burned in the lime kiln. The levels from the lime kiln include unburned TRS portion of these gases.

[c] No vent gases.

TABLE C-8

IMPACT OF CONTROLLING THE VARIOUS TRS SOURCES ON AMBIENT TRS CONCENTRATION FROM A 1350 MEGAGRAMS/DAY KRAFT PULP MILL

Source	Control Techniques	Maximum Ambient Concentration: $\mu g/m^3$ (24-hour average) Uncontrolled Level @ 0.3 km	Distance from Source (km) 0.3	0.6	1.0	1.5	2.0	Frequency - % of Concentrations Greater than 1/2 the Maximum	Percent Reduction[a]
Recovery Furnace	BLO (20 ppm)	965	40	25	15		5	29	95.9
	BLO (5 ppm)	965	10	6	4		1	29	99.0
Digester	Scrubber	870	680	230	100			48	21.8
	Incineration	870	0^b →					-	100.0
Multiple-Effect Evaporator	Scrubber	175	15	9	5			55	91.4
	Incineration	175	0^b →					-	100.0
Lime Kiln	1) Process Controls	80	20	10	6	4	3	1	75.0
	2) Process Controls + High Eff. Mud Washing	80	5	3	2	1	1	1	93.8
	3) Process Controls + High Eff. Mud Washing + Caustic Scrubbing	80	3	2	1	1	1	1	96.3
Brown Stock Washer System	Incineration	45	3		1	1		26	93.3
Black Liquor Oxidation System	Incineration	40	8	3	1	1	1	20	80.0
	Molecular Oxygen	40	0^c →					-	100.0
Smelt Dissolving Tank	Fresh Water	25	3		1	1		46	88.0
Condensate Stripping System	Scrubber	1,300	650		87	53		30	50.0
	Incineration	1,300	0^b →					-	100.0

[a] Reduction from uncontrolled average level

[b] Gases are assumed burned in the lime kiln. The levels from the lime kiln include unburned TRS portion of these gases.

[c] No vent gases.